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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE MORAINES OF SOUTHEASTERN SOUTH DAKOTA AND THEIR ATTENDANT DEPOSITS

BY

JAMES EDWARD TODD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Chicago, Ill., August 22, 1898.

SIR: I have the honor to submit herewith a report by Prof. James E. Todd on The Moraines of Southeastern South Dakota and their Attendant Deposits, which will be found to contain a large amount of valuable data relating to the later formations of that State.

Very respectfully, yours,

T. C. CHAMBERLIN,
Geologist.

Hon. CHARLES D. WALCOTT,
Director of the United States Geological Survey.

LIMITS OF REGION.

The limits chosen in the regular course of the moraine—the axial limits—are Turtle Point in Jerauld County, and a corresponding point in the northwestern part of Lake County. For convenience in reference we will name the latter Vermilion Point. Turtle Point is a conspicuous landmark, which forms a natural point of division on the west side of the loop, while Vermilion Point is on the east side of the loop in about the same latitude, and, although it is not so prominent a point of division, it is the most marked point near the northern limit of the writer's acquaintance with the moraine upon the east side. Turtle Point is upon the eastern edge of what is commonly known as the Coteau du Missouri, a region between the James and Missouri rivers spoken of by the early French explorers as the Plateau du Coteau du Missouri. The term "plateau," however, is a misnomer, for instead of a continuous plateau, it is merely the skeleton of one. The peripheral limits are, briefly, as follows: On the north, the parallel of Turtle Point, which is arbitrarily taken. On the other sides the limit theoretically coincides with that of the extreme dispersion of erratics from the portion of the moraine under consideration. On the west this boundary is most definite and is near; on the east it is confused with that of the Iowa lobe; on the south the theoretical limit is so remote that we shall need to fix an arbitrary limit, which we will take as not more than 100 miles from the moraine. A map of the region under consideration is shown on Pl. I.

Some of the advantages which may be derived from a careful presentation of this portion of the moraine are the following:

First. It gives opportunity to present in a natural and consecutive manner several typical features of drift deposits, moraines, berg drift, drainage outlets, gravel terraces, osars, etc.

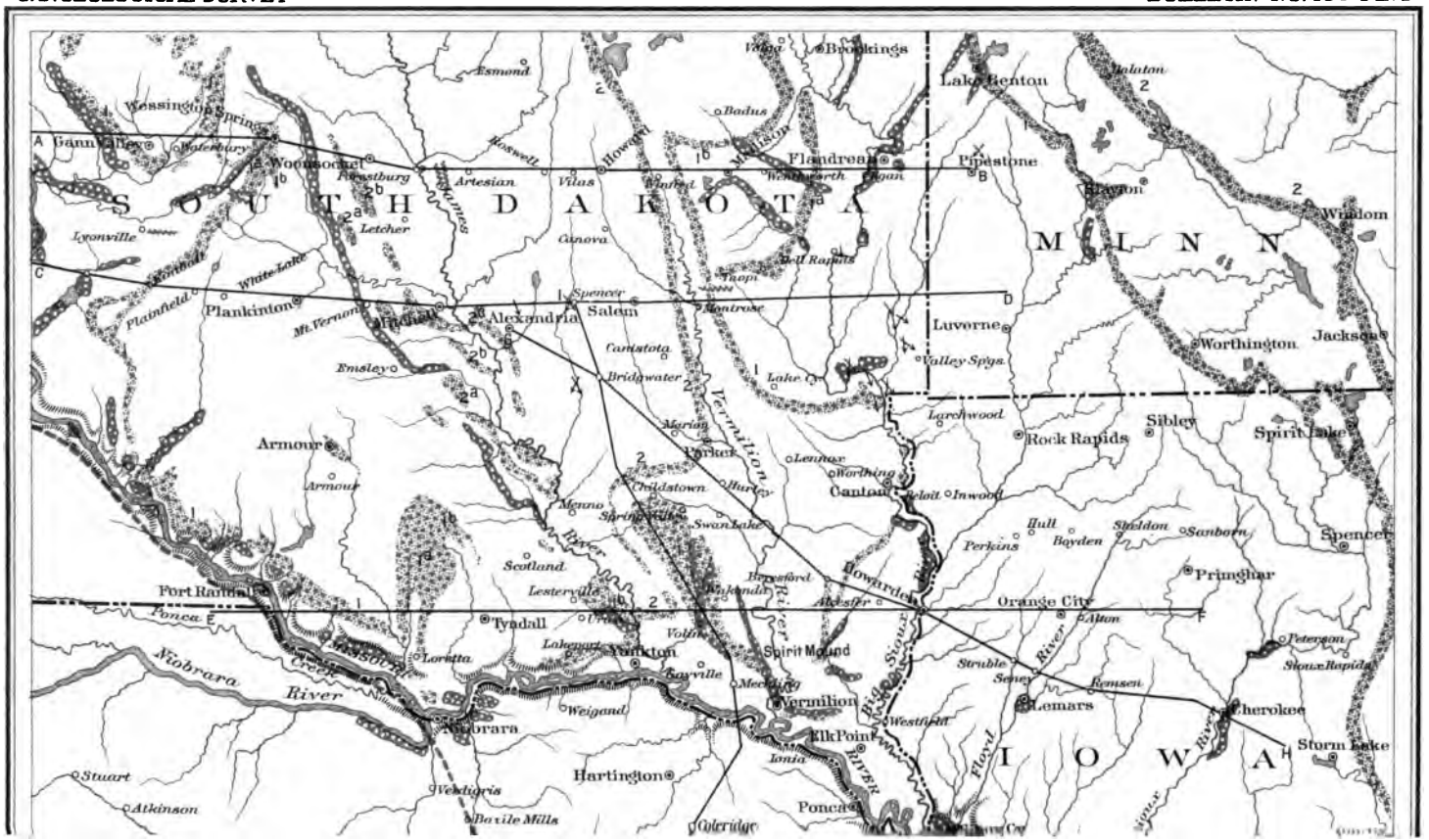
Second. It furnishes important data upon several of the open questions connected with certain Pleistocene problems, viz: The origin of loess, the distribution of glacial and glacio-natant deposits, oscillations of the earth's crust in the post-Pliocene, besides several minor questions connected with the physics and history of the glaciers.

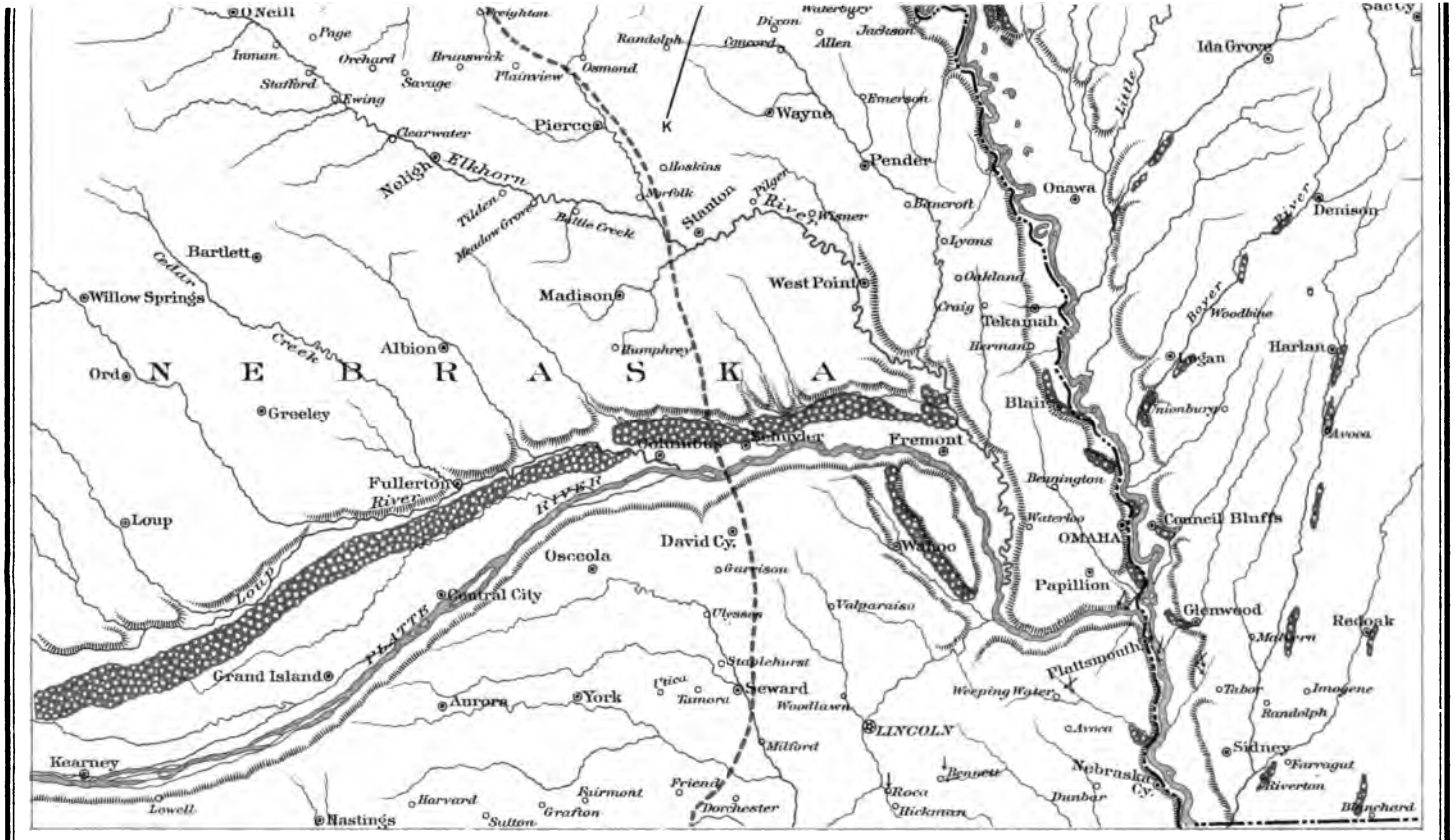
Third. It forms a convenient introduction to the larger subject which it was first proposed to present.

SKETCH OF OLDER FORMATIONS.

Though our work pertains especially to the recent deposits formed during the Pleistocene period, a brief consideration of older deposits seems important, for the underlying rocks have influenced in several ways the distribution of the drift.

The older formations belong to widely separated epochs. So far as is yet known, the region under consideration exhibits only strata belonging to the Algonkian and the Cretaceous, with scattered fragments of


SOUTH DAKOTA
MINN
IOWA
Brookings
Lake Benton
Flandreau
Pipestone
Esmond
Badus
Watertown
Lake Benton
Kossington
Spring Valley
Gann Valley
Woonsocket
Artesian
Vilas
Howard
Winfred
Wentworth
Egan
Canova
Letcher
Lyonsville
Plankinton
Mt. Vernon
Alexandria
Salem
Spencer
Montrose
Bell Rapids
Trojan
Luverne
Valley Spgs.
Worthington
Jackson
Wisdom
Emsley
Bridgewater
Canistota
Lake Cochrane
Larchwood
Rock Rapids
Sibley
Spirit Lake
Armour
Marion
Parker
Lennox
Worthington
Canton
Inwood
Hull
Sheldon
Sanborn
Spencer
Perkins
Bayden
Pringhar
Scotland
Lesterville
Fort Randall
Tyndall
Orange City
Alton
Peterson
Sioux Rapids
Loretta
Yankton
Spirit Mound
Vermilion
Lemars
Cherokee
Storm Lake
Niobrara River
Missouri River
Big Sioux River
Floyd River
Weigand
Elk Point
Westfield
Ionia
Stuart
Atkinson
Hartington
Verdigris
Bazile Mills
Coleridge
Ponca
Struble
Remsen



PLEISTOCENE DEPOSITS OF SOUTHEASTERN DAKOTA AND ADJACENT REGIONS

BY J. E. TODD, 1898

A. Hoen & Co. Lith. Baltimore.

X STRIÆ. MORAINES. TERRACES AND OLD CHANNELS. OSAR RIDGES. LIMIT OF NORTHERN OR GLACIAL DRIFT.

Note: Numbers on this map denote comparative age of moraines

Tertiary deposits. The Algonkian—or, as it has been considered by Prof. N. H. Winchell, the lower Cambrian—is represented only by the red quartzite, which is conspicuously exposed along the Big Sioux, and was named several years since by Dr. C. A. White the Sioux quartzite. The exposures in this region appear to be portions of an irregular syncline, extending from southwestern Minnesota to the James River. An enumeration of localities will be found on another page (p. 122). The strata have usually but slight dip, rarely more than 6°. Ripple marks are frequent, but no fossils, except a few of doubtful character, have yet been found.[1] The rock bears evidence of ebb-and-flow structure. Oblique stratification, inclining in different directions, abounds in some strata. Thin seams of metamorphosed clay occur occasionally, the more notable being the "pipestone," at Pipestone, Minnesota. The lower stratum exposed on Wolf Creek is a bed of unconsolidated sand, evidently once consolidated but now decomposed.

The Cretaceous rocks all belong to the Dakota group and to the three members separated by Hayden, but combined by King into the Colorado group.

The first, the Dakota sandstone, is exposed along the James River and its tributaries in Hutchinson, Hanson, and Davison counties and along the Missouri below Ponca, Nebraska.

The Benton group, comprising dark pyritiferous clays, is certainly found exposed only along the bluffs of the Missouri, from near the mouth of the James River to the vicinity of the Big Sioux.[2] Slight exposures near Milford, Nebraska, and Rockport, Dakota, also possibly belong to this group.

The Niobrara of Hayden, the chalkstone, forms a more conspicuous and important deposit, which extends very widely under the drift. It is exposed along the Missouri from Chamberlain to St. Helena; along the James and its tributaries in Hanson and Davison counties; at several localities along Clay and Turkey creeks; upon Beaver Creek, near Canton; on the Split Rock, north of Brandon; along the Big Sioux, at Akron and below, comprising the Inoceramus beds of White, and along Brule Creek, in Union County.

The Pierre group, consisting of clays of different colors and qualities, probably occupies four-fifths of the surface underneath the drift. It is exposed along the Missouri from near the mouth of the Niobrara to the northern limits of the region. It is this formation which is struck in wells which pass through the drift in all localities in the Dakotas east of the Missouri, except those that have been already indicated.

The Tertiary rocks are represented by the greenish quartzite—well shown at the Bijou Hills—and various beds of sand, gravel, and clay that are associated with it. These are ascribed to the Loup River group by Dr. Hayden, and no reason for questioning the determination

[1] Prof. N. H. Winchell, Thirteenth Ann. Rept. Geol. Nat. Hist. Survey Minnesota, 1884.
[2] Cf. Hayden, 1870, p. 87.

has come to the writer's knowledge.[1] Distinct fossils were not noticed by him in it, though pieces of petrified wood and of mammalian bones have been noticed upon it, which may have been derived from it. It contains greenish pebbles of pitchstone at many points. In northeastern Nebraska the Loup River Tertiary is represented by over 80 feet of sands, marls, and clays containing petrified shells and bones of animals. From similarly situated beds north of Sioux City teeth of *Equus major* have been reported by Mr. Bain, who referred the beds to the Pleistocene.[2]

The Cretaceous clays have contributed largely to the mass of the till. The Tertiary rocks have been influential in the formation of buttes which have had an important limiting and directing influence upon the ice sheet. The Archean rocks have been less influential, not having been prominent enough to limit or deflect the ice, nor sufficiently yielding to contribute material of much volume. In a few cases, as at Rockport and near Alexandria, they seem to have exercised considerable directing power upon the lower portion of the ice.

ELEVATIONS.

The elevations which form an important portion of this paper were mostly taken with an aneroid barometer. A few are derived directly from railroad profiles. The more important elevations have been taken either several times or on days when the barometer showed little fluctuation. In general their accuracy corresponds to their distance from important streams or from railroads. A few are taken from the topographic surveys of the United States Geological Survey. At the beginning of our work the number of railroad elevations in the region under consideration was quite small, on account of its recent settlement. But the rapid railroad building of the last few years has been favorable to the work, both by furnishing exposures and in affording fresh and accurate information concerning elevations. The accuracy of the survey has been materially aided through the generous response on the part of railroad engineers to requests for profiles. In the appendix several of these are published for the first time.

ACKNOWLEDGMENTS.

I would hereby gratefully acknowledge my indebtedness to Mr. D. J. Whittemore, chief engineer of the Chicago, Milwaukee, and St. Paul Railway Company, for a carefully prepared list of elevations of all stations and bridges over important streams along its lines in the States of North and South Dakota; to Mr. E. Gerber, assistant engineer of the Fremont, Elkhorn and Missouri Valley Railroad Company, for elevations upon all its lines in Nebraska, a section of the Missouri River at Blair, and other favors; to Mr. C. W. Johnson, chief engineer

[1] Gen. G. K. Warren's preliminary report on Nebraska and Dakota, p. 78.
[2] Iowa Geol. Survey, Vol. V, p. 277.

of the Chicago, St. Paul, Minneapolis and Omaha Railway Company, for elevations of all stations on its lines in Nebraska, and a section of the Missouri at Sioux City; to Mr. B. B. Colborne for a profile of a preliminary survey from Chamberlain, Dakota, to Lemars, Iowa; to Mr. George A. Lederle for a section of the Missouri at Omaha; and to Mr. J. H. Charles, of Sioux City, for obtaining elevations on the Sioux City and Northern Railway and the Pacific Short Line. I would also express gratitude to Hon. Alexander Mitchell, of the Chicago, Milwaukee and St. Paul Railway Company, and to Hon. Marvin Hughitt, general manager of the Chicago and Northwestern Railway Company, for favors shown in transportation.

CHAPTER II.

FIRST (OUTER) OR ALTAMONT MORAINE.

This is first presented because it furnishes a convenient line of reference in the further treatment of the area under consideration. It is also the best defined and most constant feature.

COURSE OF THE MORAINE.

The accompanying map, Pl. I, with a brief explanation, will give a comprehensive view of the direction and divisions of the moraine.

Beginning at Turtle Point, in Jerauld County, the head of a prominent interlobular portion, the moraine extends in a south and southwest direction past the Bijou Hills, nearly to the junction of Pratt Creek with the Missouri, where there is a gap a few miles in breadth. The more notable variation from a direct course is a small loop pushed westward toward Red Lake.

East of Pratt Creek the moraine appears again in the Cedar Creek Hills, which, lying on both sides of Cedar Creek, form a high V-shaped reentrant angle, pointing northeast. From the eastern end of the V the moraine extends in a general southeasterly direction, nearly to the junction of Wet Choteau and Dry Choteau creeks, where it crosses the former, turns sharply northward, and forms a long interlobular portion around the latter stream, being known as the Choteau Creek Hills. Below the junction of the Choteaus the moraine lies along the west bank of the stream nearly to its mouth, where it crosses and continues close along the bluffs of the Missouri to a point opposite the mouth of the Niobrara, where it develops a slight reentrant angle.

From this point no trace of it is found on either side of the Missouri until we pass below Bonhomme. A little east of that place, on the north side of the Missouri, it appears again, and, after forming a long and much-eroded loop to the east, reaches Lesterville, where, after forming a much smaller similar loop, it takes a southeasterly direction. About 6 miles east of Yankton it swings more to the east, crosses the James River, and continues to a broad gap through which Clay Creek passes. East of the Clay Creek Gap it reappears along the east bank of that stream and runs north and northwest to the vicinity of Childstown, where it again doubles upon itself and takes a quite direct course southeast to Spirit Mound, 6 miles north of Vermilion, forming Turkey Ridge.

East of Spirit Mound no trace of it is found until Brule Creek is reached, 10 miles east. There it reappears, running northward to Beres-

ford, and thence north-northeast to the vicinity of Canton. From that place to the vicinity of Sioux Falls it seems not to have been formed, except at three or four isolated points. About 5 miles east-southeast of Sioux Falls it reappears on the west bank of the Big Sioux, and curves around the bend of the Big Sioux at Sioux Falls, and thence west and northwest to the vicinity of Montrose. From there it lies along the east side of the East Vermilion River to Vermilion Point, about 12 miles northwest of Madison. There it forms a reentrant angle by turning sharply to the east.

The map represents also the course of the moraine for some distance outside the limits chosen.

FROM TURTLE POINT TO PRATT CREEK.

We have found it convenient to begin at the prominent headland in Jerauld County known as Turtle Point. A view of this from the

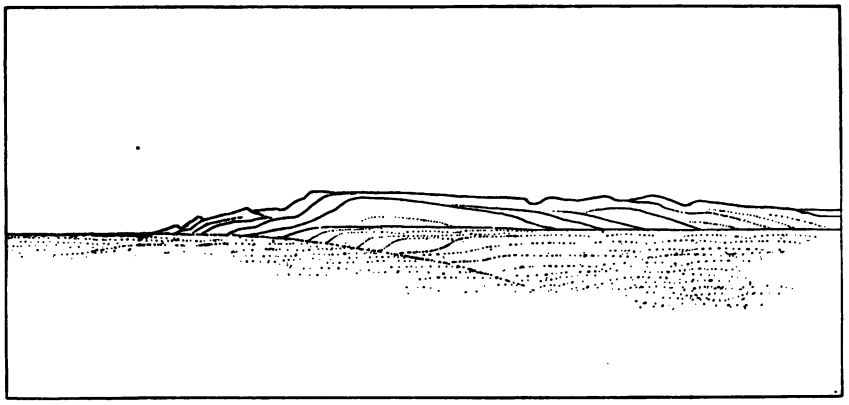


FIG. 1.—Turtle Point, from the northwest.

northwest is given in fig. 1. This forms the northern end of a high, even-topped ridge which extends from sec. 35, T. 108, R. 65, to the southern portion of T. 106, R. 65, a distance of 12 miles.

The point derives its name from the unique figure of a turtle, 1 rod in length, formed upon a mound capping the summit of the point. This figure is formed of small bowlders placed at short intervals so as to describe the outline of a turtle. The range extending south we shall call Turtle Ridge (Pl. II). Its height above the plain to the east is nearly 500 feet. Its eastern face is quite abrupt, and along its northern portion is much marked by gulches, which arise from springs issuing from beneath the drift. One of them is known as Wessington Spring, which pours forth a copious supply of slightly sulphurous water.

These gulches seem very subject to landslides, which have repeatedly changed the location of the springs. This tendency to slide is probably the effect of water softening the clays below. Some of

these springs are connected with long, trough-like ridges. One, in particular, running east from an old exit of the Wessington Spring, is extraordinarily large. It extends eastward from the face of the ridge, 1½ to 2 miles, with a height midway of from 50 to 75 feet above the adjacent slope.

The western side of the Turtle Ridge subsides with a gentle slope to a broad, undulating plain, around the heads of Smith and Crow creeks.

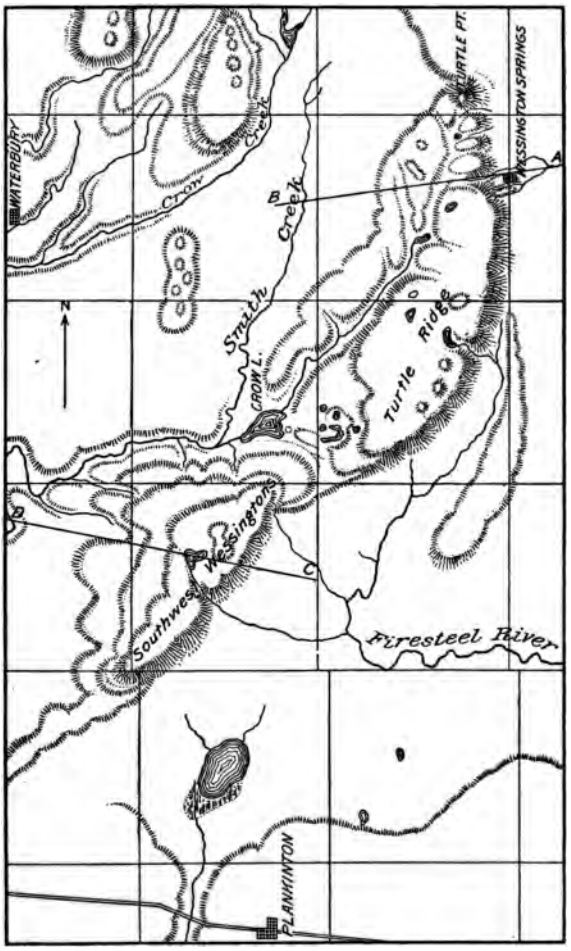
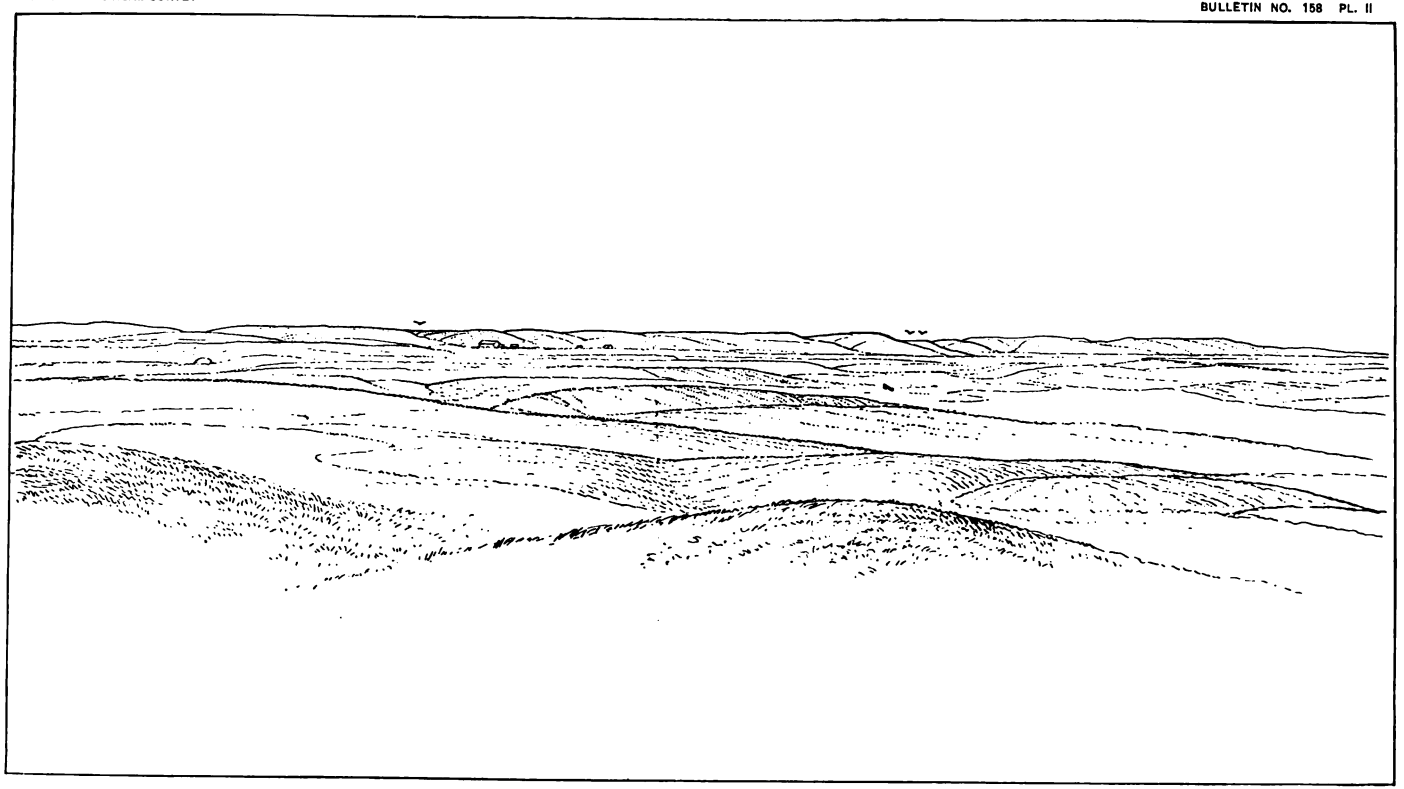


FIG. 2.—Map of Turtle Ridge and southwest Wessingtons.

This plain is considerably eroded near these streams. The top of Turtle Ridge is in several places rough and very stony, exhibiting the characters of a typical moraine. This is especially true toward its western side at the north end, and along the eastern side farther south. Among these knobs are frequent basins, some of them containing water.

A very remarkable feature in this ridge is a long, deep, narrow val-



VIEW OF TURTLE RIDGE FROM THE EAST.

v Wessington Spring Gulch. vv Gulch connected with ancient channel (see fig. 2 and Pl. III).

ley, with abrupt sides, extending from near the north end through the center of the ridge 6 or 7 miles toward the south. It then turns abruptly to the southwest and flows into Crow Lake. Tributary valleys beginning at the face of the hills, on either side, form with this central valley a complete drainage system. In the main channel are a few isolated domes 25 or 30 feet in height, apparently composed of gravel and bowlders. At different places in the channel are basins containing water which form considerable lakes, and are not improbably the sources of supply for the springs before mentioned. Muskrat Lake is possibly the principal supply of the Wessington Spring. Some of the ancient water channels have recently been eroded by water flowing eastward, either upon the surface or by springs cutting backward into the hills. A conspicuous example is represented in Pl. III.

The general arrangement of the drainage system is shown in the accompanying map, fig. 2.

An interesting question which may be conveniently discussed at this point is: How much of these high portions of the moraine is due to glacial action and how much to pre-Glacial topography? Turtle

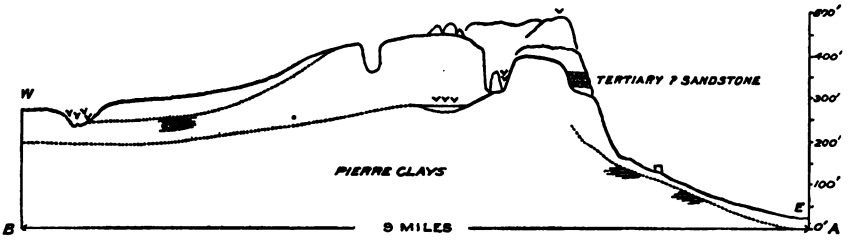


FIG. 3.—Transverse section of Turtle Ridge. v Turtle Point. vv Ancient channel leading to Crow Lake. vvv Crow Lake. vvvv Smith Creek.

Ridge affords several features which indicate that the glacial action has been the least efficient of the two—in other words, that the position and the greater portion of the mass are due to erosion antedating the glacier. As will be seen from the accompanying section fig. 3, there are exposures of sandstone in the east front of the hills in sec. 12, T. 107, R. 65. This sandstone is evidently similar to that capping the Bijou Hills and the buttes farther west. The deposit is not consolidated into a quartzite, as is usual in such localities, but shows similar structure even to the occasional occurrence of beds of grit between the finer layers.

Below the beds of sandstone are lead-colored clays, occasionally exposed in the deepest portions of the gulches. A more striking evidence of their existence is seen in the numerous landslides which have occurred near the various springs. The sulphurous ingredients of the waters are probably traceable also to the pyrites in the clays. Along the east foot of the ridge the drift is thin, and wells frequently reach the Cretaceous clay 15 to 20 feet below the surface.

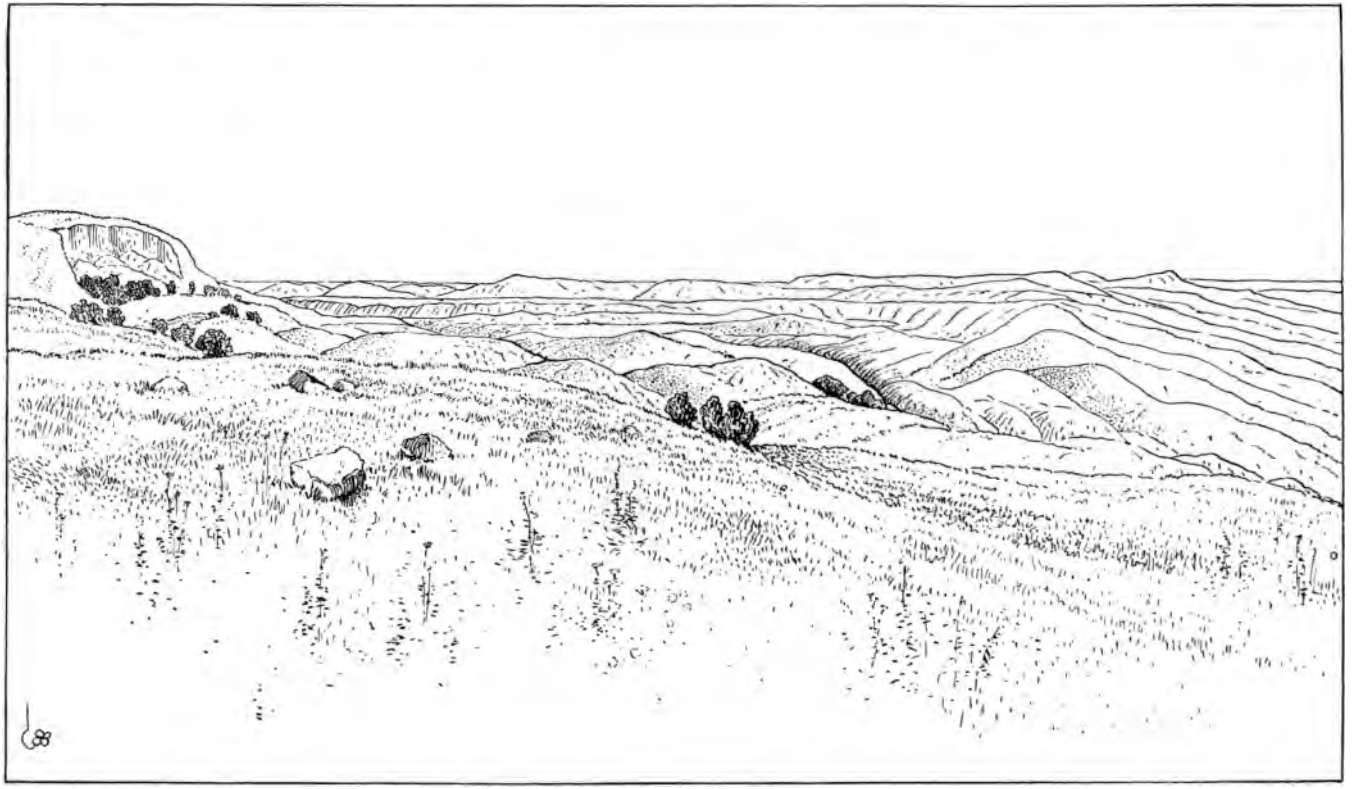
Another evidence of the influence of pre-Glacial topography is seen in the configuration of the country north of Turtle Ridge. Extending northwest is the edge of a terrace, quite distinctly marked, about 250 feet above the level of the plain on the east. This terrace is covered with drift, and its edge is seamed with gulches, which are faint imitations of those in Turtle Ridge. It also abounds in bowlders, some of considerable size. A ready explanation of this feature would be that it marks the former edge of a great valley, more commonly known as the James River Valley, and that the force of the ice sheet was sufficient to override this portion because of its lower altitude, while Turtle Ridge was able to hold its own against it.

Before proceeding further we may find illustrated in Turtle Ridge an interlobular moraine, as defined by Professor Chamberlin. It occupies the space between the shallower western lobe and the main body of the great Dakota lobe on the east. The internal drainage system already described was evidently occupied by superglacial streams which entered it from either lobe and drained through Crow Lake into the present valley of Smith Creek. That these streams were of considerable size is indicated by the fact that the breadth of some of the outlets upon the face of the moraine is from 150 to 200 yards. These valleys are flat bottomed, 90 to 100 feet in depth in the deepest portions. The gravel mounds before mentioned were possibly formed by eddies in the stream. A similar internal drainage is found in the Ree Hills, Bald Mountains, and other interlobular moraines. Muskrat Lake is apparently formed by the partial filling of the principal channel by material brought in by the main western branch.

Among the bowlders found scattered in the Turtle Ridge two very large limestone bowlders were noted on the east brow of the hills, one 9 by 7 by 2 feet, the other 20 by 9 by 2 feet. There are no bowlders of red quartzite, nor of local Tertiary quartzite and sandstones. Ordinary granite and greenstone bowlders abound.

Extending southward from near the middle of the east side of Turtle Ridge is a low morainic ridge, leaving it at a very small angle, and running 3 or 4 miles farther south, and subsiding gradually to the level of the eastern plain in the northern part of T. 105, R. 65. Between this and the principal range is a shallow valley occupied by the headwaters of the west branch of the Firesteel. This subordinate ridge is very stony. Whether the explanation of its existence may be similar to that of the terrace north of Turtle Ridge is uncertain. It seems not unlikely that it is a portion of a faint minor moraine found between the first moraine and the second, or it may be a subglacial moraine due to some unevenness in the floor over which the ice was moving.[1] Extending from a point about a mile south of Crow Lake to a point 3 or 4 miles west of White Lake, in a nearly direct line, is the axis of another high and massive ridge, which we will call the south.

[1] Cf. Dana, Am. Jour. Sci., 3d series, Vol. XXVIII, p. 230.



VIEW OF OLD OVERFLOW CHANNEL IN TURTLE RIDGE.

Turtle Point on the right.

west Wessingtons. Its eastern face, like that of Turtle Ridge, is steep for about two-thirds of its height, then descends by gentle slope to the plain southeast. This range is highest in the middle, where it has an elevation of about 300 feet, in the vicinity of Ishams Lake. Its western slope is not more than half as steep as its eastern, and declines gradually to Smith Creek, about 5 miles northwest, where the stream is over 100 feet lower than White Lake in the plain east, inside of the moraine, fig. 11 (p. 37). While the range is massive, its summit is crowned with a few clusters of knobs, showing at a distance its morainic character. Among these knobs are the usual basins and ponds, the largest of which is Ishams Lake, sec. 16, T. 105, R. 66. Between Turtle Ridge and the southwest Wessingtons there is a broad sag, the summit of its bottom being about 100 feet above the plain southeast. In about the center of this pass or sag is a remarkable system of sharp, stony ridges from 10 to 30 feet in height, extending from near the southeast corner of T. 105, R. 66, in a curve corresponding to the lower portion of the sag to the southeastern part of Crow Lake. The general features of the system may be more fully understood from the accompanying map, fig. 4:

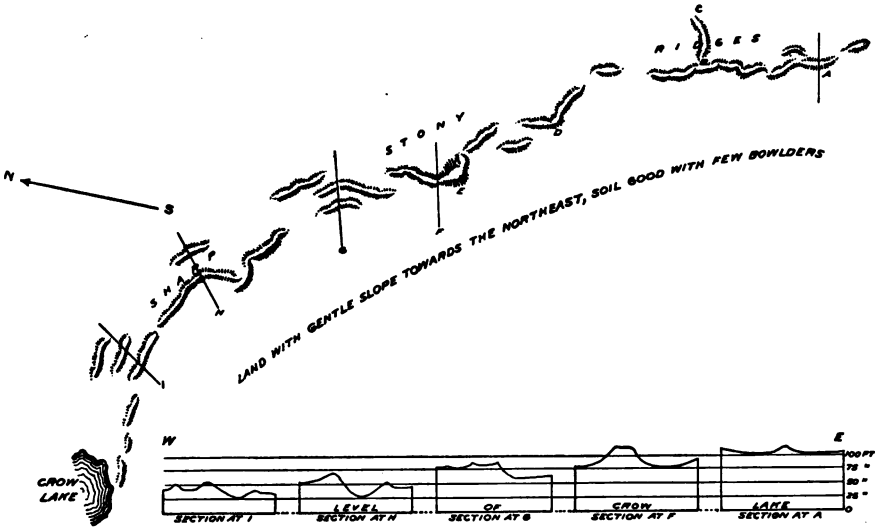


Fig. 4.—Map of osar-like ridges near Crow Lake.

These stony ridges are osar-like and are probably connected with former drainage from the ice sheet.

At the southern end of the southwest Wessingtons is a similar but less marked pass through the moraine, by which water probably escaped into a valley connecting with the head waters of Smith Creek. From this outlet the moraine is less conspicuous, evidently not having so high a pre-Glacial surface on which to rest. A scattered series of morainic hills may be traced southwest past Kimball to the middle of

the western side of T. 103, R. 68. This system of hills is from 2 to 5 miles in breadth, its inner and outer limits not being very clearly defined. Along its outer limit west of Kimball is a valley running southwest, connecting the valley of American Creek with Red Lake and the Missouri. The inner ranges of the moraine are but little higher than the subdued swells of the glacial topography upon that side. About 4 miles east of Kimball the railroad crosses two well-defined valleys, which head on the inside of the moraine. They doubtless indicate lines of drainage dating back to the time of the ice sheet. One of them connects with American Creek and the other with Smith Creek.

From near the middle of the west side of T. 103, R. 68, these morainic ridges begin to describe a semicircular curve toward the northwest, the outer range of which lies about along the east side of Red Lake. The principal ridge in the curve presents an abrupt and stony inner slope and a gentle outer slope, with few bowlders. From the south-

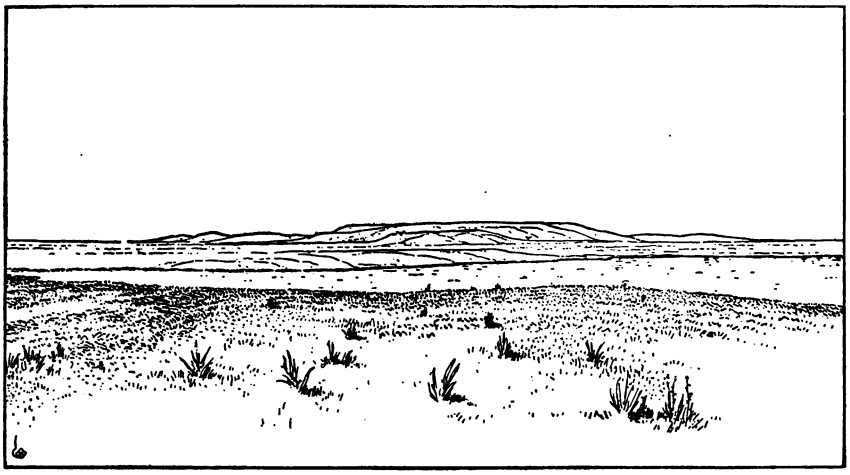


FIG. 5.—Portion of the moraine near Bijou Hills. v Moraine.

ern terminus of this semicircle, near the southern line of T. 103, R. 69, the moraine seems still less defined, but as it approaches the east end of the East Bijou it regains its character of broad, stony ridges separated by sags with ponds, the ridges being from 30 to 40 feet higher than the plain within. Lying against the eastern end of the East Bijou is a high north-and-south ridge over 100 feet in height (fig. 5), and apparently composed entirely of drift. South of the East Bijou the glacier at some time evidently pushed farther west, perhaps nearly to the western end, but such occupation was comparatively temporary. Masses of bowldery clay are found on the highest summit of the East Bijou, toward the south side and near the southwest angle of the hill. South of the Bijou Hills the moraine is again ill defined.

On or near the middle of the western line of T. 100, R. 69, is a well-

defined north-and-south ridge extending 2 or 3 miles. Its height is over 100 feet. Its northern end terminates rather abruptly amid a cluster of ponds of considerable size.

Extending inside of the principal portion of the moraine, from near the northwest corner of T. 101, R. 68, 7 or 8 miles, in a south-by-east direction, is a remarkable chain of lakes or lake beds occupying a broad, shallow valley. Southwest of the east end of the East Bijou is another cluster of lakes, with a valley connecting them with the head waters of Snake Creek. It is probable that these two systems of lakes occupy an old channel leading into Snake Creek.

Northwest, west, and south from the short ridge last described are lower stony ridges, which are doubtless a portion of the moraine. Besides these we find no trace of the moraine till we reach the hills around Cedar Creek, which occupy the central portion of T. 98, R. 68. The plain on the inside of the moraine is quite even, extending sharply down to the east bank of the Missouri. In it Pratt Creek has excavated a narrow valley about 200 feet in depth. East of its junction with the Missouri there is a high terrace, capped with an abundance of gravel and bowlderets.

FROM PRATT CREEK TO RUNNING WATER.

The Cedar Creek Hills receive their name from a very short stream called Cedar Creek, which is surrounded by them. They extend some-

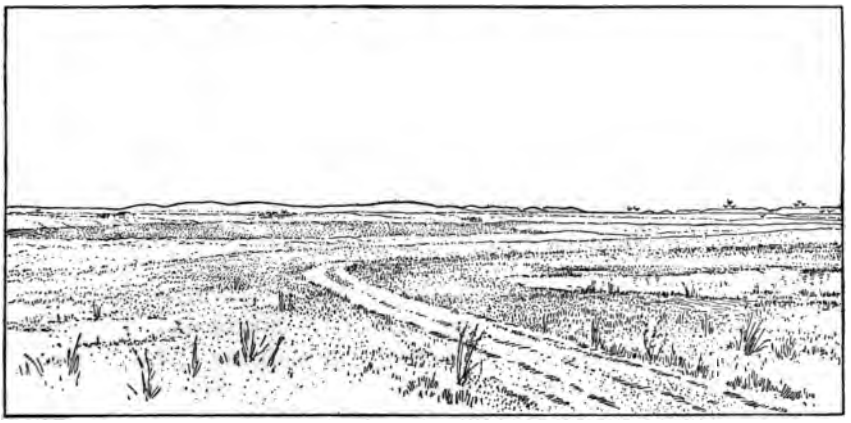


FIG. 6.—Cedar Creek Hills, from the north. v Pratt Creek. vv Missouri River. v'v Driftless bluff.

what in the form of a V, with its apex pointing northeast and subsiding gradually into the plain on or near sec. 15, T. 98, R. 68 (fig. 6). The northwestern arm of the V, which is not very prominently developed, extends for 2 or 3 miles along the northern side of the stream. The southeastern arm extends in an irregular manner southward along the top of the east bank of the Missouri, connecting with the hills northeast of Wheeler. This continuation of the moraine has been under-

mined by an east bend of the river above Wheeler until apparently half of the moraine has been removed. Its appearance is shown in fig. 7. This view presents the nearest approach of the inside of the moraine to the Missouri River at any point between Pratt Creek and Choteau Creek.

From this point, which is on or near sec. 23, T. 97, R. 68, the inner line of the moraine may be described as follows: It extends east-southeast to the southwestern end of Lake Andes, thence from the southwest corner of sec. 12, T. 69, R. 65, near the south shore of Lake Andes southward along the east side of the township nearly to its southeastern corner, and thence south-southeast in nearly direct line to the middle of T. 94, R. 62.

The structure of the moraine through this portion is found to be a deep deposit of drift, overlapping hills of Cretaceous clay. The moraine

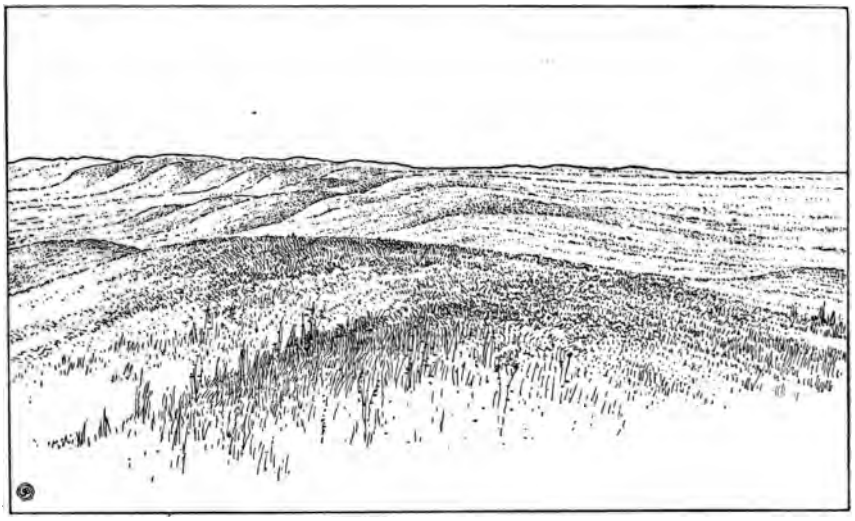
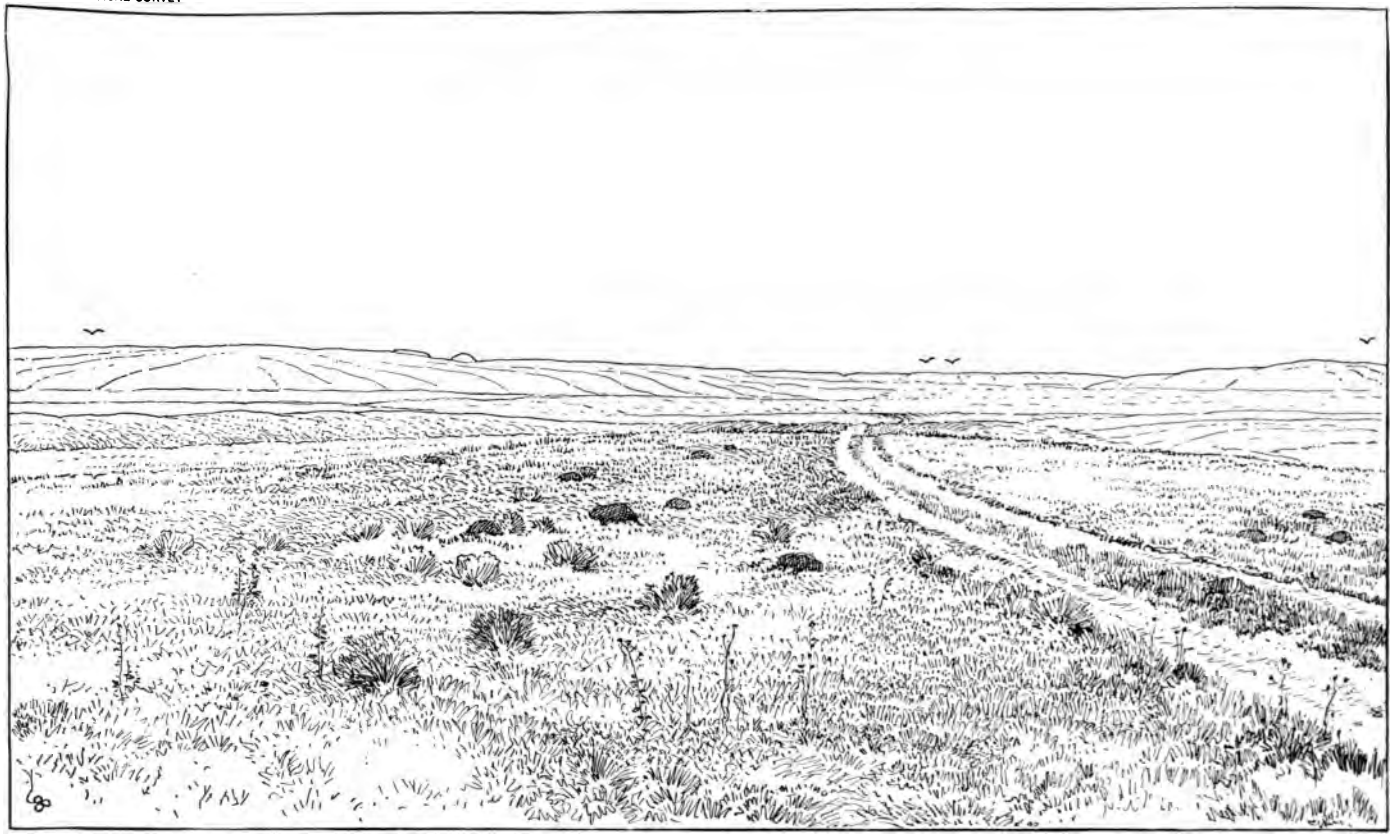


FIG. 7.—The moraine half eroded by the Missouri.

presents few knobs upon its surface. It may be described as a broad swell, with a somewhat abrupt slope toward the northeast and an irregular gentle slope toward the southwest, which latter is much seamed by short streams draining into the Missouri. It is interesting to find this portion of the moraine mapped as a ridge on Gen. G. K. Warren's map of 1857.

Through it are three important outlets, extending upon or a little below the level of the plain northeast. The first of these is now occupied by Pease Creek and another smaller stream. This outlet is from one-half mile to 2 miles in width, and is flat-bottomed, especially upon the western side, the eastern being occupied largely by a system of high, stony hills resembling osars. Another outlet is that extending southwest from the end of Lake Andes (Pl. IV). This also is occupied



LAKE ANDES OUTLET FROM THE NORTHEAST.

v Moraine. v v Bluffs across Missouri River, showing through Lake Andes Gap.

by a small stream, which flows along the western side, and also a dry drainage channel, a few feet in depth, from Lake Andes itself. The eastern side of this outlet also presents prominently the effects of running water, in the form of gravel terraces. Another less important outlet extends west-southwest from near sec. 25, T. 96, R. 65, till it joins the Andes Outlet before it reaches the river. From its relation to a grassy lake of considerable size northeast of it in the plain, I have called this Grass Lake Outlet. All of these outlets present the features of nearly straight troughs, with sides quite abrupt, especially the western. Their bottoms are in every case lower than the general level within the moraine, and slope more or less rapidly to the surface of the lower gravelly terrace described in Chapter V. Near the head waters of Sevenmile Creek, at the southwest corner of T. 96, R. 64, the moraine declines in elevation from 75 to 50 feet, and at the same time seems to broaden, and continues this character from this point to Choteau Creek. Several streams have their valleys heading in close to the northeast

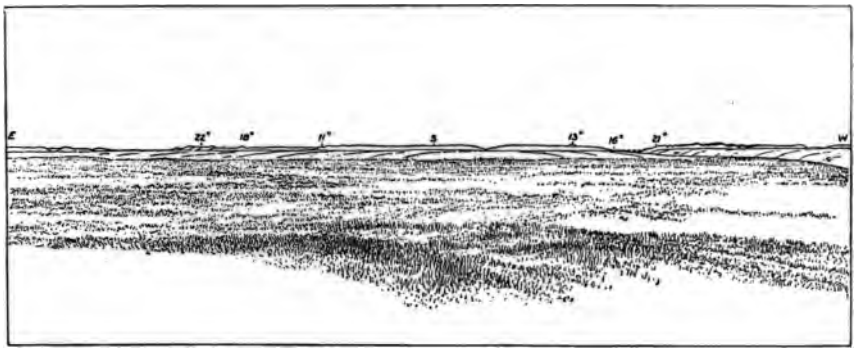


FIG. 8.—General view of the moraine from 2 miles south of Grandview. Numbers indicate degrees from south.

side of the moraine and probably were minor channels of overflow when the ice was forming the moraine. A distant and general view of this part of the moraine is shown in fig. 8.

A conspicuous point in this lower portion of the moraine is on or near sec. 30, T. 94, R. 62. It is situated some distance outside of the inner boundary of the moraine, so that it seems never, or very briefly, to have been covered by the ice. It presents the well-marked layers of the Bijou quartzite, lying in horizontal position, and scattered upon them numerous bowlders of all kinds. Its altitude is quite definitely determined to be 1,675 feet.

A view from the summit of the moraine shows, in general, a gentle slope down to the level of a high terrace along the left bank of the Missouri. This terrace averages over 200 feet above the river.

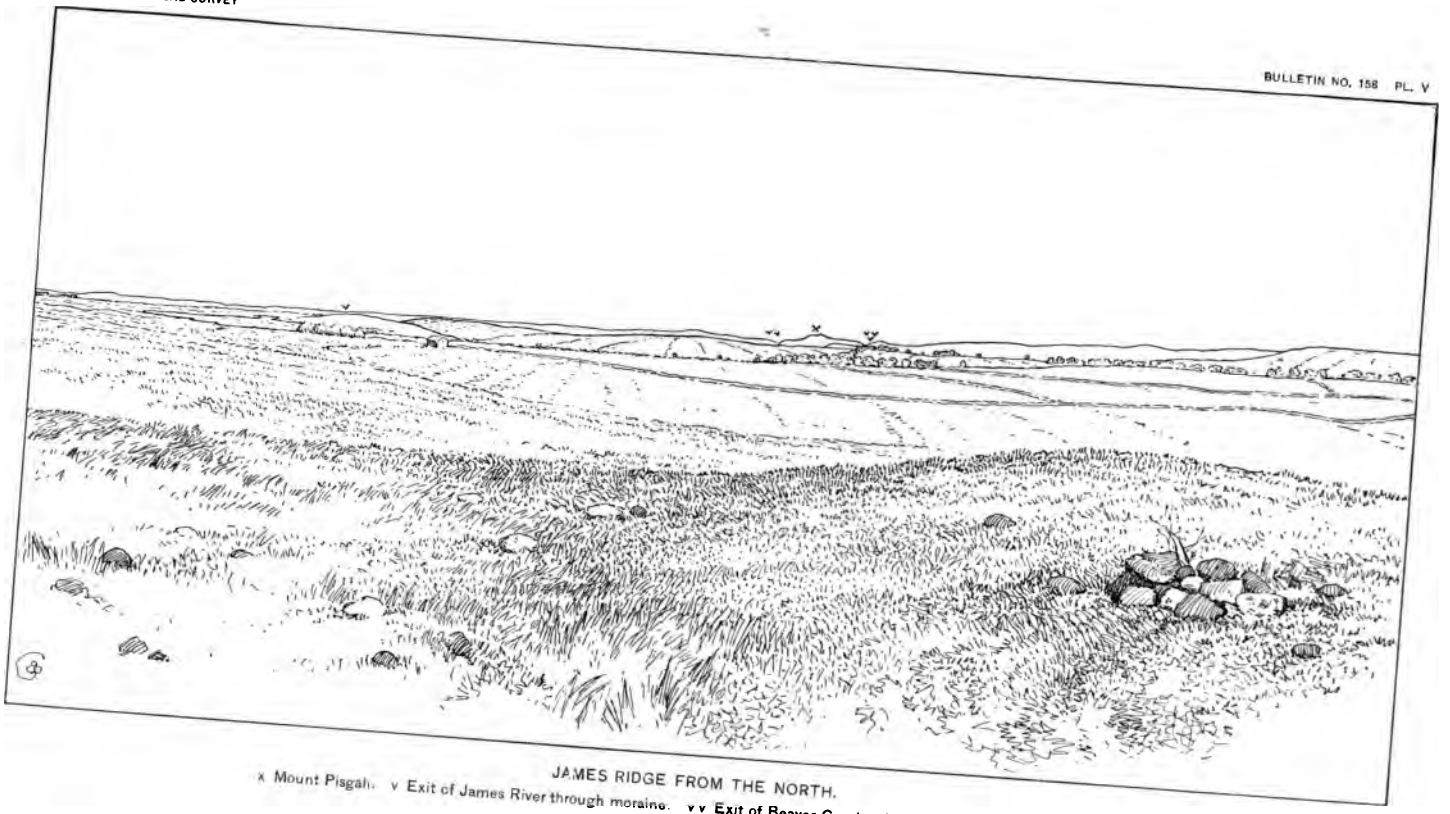
The valley of Choteau Creek, as it approaches the moraine, is from 1½ to 2 miles in width and flat bottomed, apparently marking another outlet, which, however, instead of going straight toward the Missouri, turns

eastward and joins a drainage valley from the interior of the Choteau Creek Hills. This latter valley, from the scantiness of water in it, is known as the Dry Choteau, while the more extended western branch is locally known as the Wet Choteau. The Choteau Creek Hills are a system of morainic hills surrounding the Dry Choteau. They extend north and south and are estimated to be 3 to 5 miles in width. Their northern end occupies the west half of T. 97, R. 61, and is surrounded with a broad, semicircular valley, in which rise the headwaters of Emanuel Creek on the east and an important branch of the Wet Choteau on the northwest. This valley is most abrupt on its outer side, and has a depth of 60 to 100 feet below the plain outside. The plain ends in a terrace-like edge, in some places considerably raised above the region farther back. This is markedly true of the portion east of the hills, near Aden post-office, sec. 1, T. 97, R. 61, where the surface suggests a minor moraine. The hills terminate southward in narrow but prominent ranges near the mouth of Dry Choteau. This is particularly true of hills on the east side of the system. East and southeast of that point there is a broad swell, evidently passed over by the ice and suggesting an advance of the ice farther west in its later occupation of the region. Perhaps the erosion of the waters escaping from the valley had removed the moraine on that side, so that the ice broke over the remainder into the drainage valley itself. That their location was probably predetermined by hills of Cretaceous clay is indicated by the reported occurrence of chalkstone some distance above their base at the northern end. This was not certainly determined to form a ledge, but was found in such quantity as to render it quite certain that such was the case. Several important lakes and marshes occur in the hills.

The ice sheet evidently very nearly surrounded these hills, as the small lobe extending east of them pushed through quite to Choteau Creek in T. 93, R. 61. It also reached nearly to the present course of the Missouri. There are, however, high northwest-southeast ridges extending from near the mouth of Choteau Creek to sec. 3, T. 92, R. 61, where they are more developed than farther west, rising over 150 feet above the plain to the northeast and estimated to be fully 400 feet above the river to the north. They are so cut by ravines from the river as to make their morainic character somewhat questionable. Fortunately, in an old well evidence was found of an ancient pond upon this hill, containing specimens of fresh-water shells and having every appearance of a morainic basin, which had been filled with earth 8 or 10 feet in depth.

EMANUEL CREEK GAP.

From this point no trace of anything that can be called a moraine is found until we reach the bluffs about 5 miles east of Bonhomme. Over this region, on the north side of the river, the plain, gently undulating, gradually subsides to the level of the lower, bowldery terrace,



JAMES RIDGE FROM THE NORTH.

x Mount Pisgah. v Exit of James River through moraine. vv Exit of Beaver Creek. $\frac{vv}{v}$ Entrance of Beaver Creek.

which has an altitude of about 200 feet above the river. The surface is somewhat lower in the vicinity of Springfield. North of Bonhomme, in the valley of Snatch Creek, the general surface is still more depressed, and abounds in low bowldery knobs. It suggests the filling of a pre-Glacial valley. This is further indicated by a gap in the chalk bluffs along the north side of the Missouri.

Upon the south side of the river, back from the bars and bottom land immediately adjacent to the channel, is a strip of country from 2 to 4 miles in width displaying very little drift, and underlain by chalkstone below and Cretaceous clays above, with much sand, probably of Loup Fork epoch, still higher. This region is very much eroded by small streams running north to the river. South of this strip of country there rises abruptly the northern edge of a table-land, built of beds of sand and gravel below and of loess with a few scattered bowlders above. The loess is much eroded, but its valleys extend away from the river into the branches of Bazile Creek. One peculiar feature of the northern edge of this table-land is the projection of high ridges of the loess extending 1½ to 2 miles northwest, without diminishing in altitude, over the Cretaceous region before described.

It seems clear that in this gap of the moraine we have trace of a relation of ice sheet and river similar to that which existed between the Bijou Hills and the Cedar Creek Hills, though on a vaster scale: with the difference, however, that in that case the water was flowing rapidly transversely to the motion of the ice, while in this case it was, perhaps, discharging more in the same direction.

FROM BONHOMME TO SPIRIT MOUND.

The moraine appears on the north bank of the river, about 5 miles east of Bonhomme, in a high, broad swell, extending from the southwest toward the northeast, past Lakeport, which is situated on the inner crest of the moraine; but it rather abruptly turns eastward and declines in height near the center of T. 94, R. 57, where there seems to have been a broad outlet, or perhaps a tongue of the ice in the place now corresponding to the upper valley of Beaver Creek. Later there seems to have been much water flowing southeast over this area.

Near Lesterville a considerable cluster of morainic hills again appears, about 50 feet in height above the plain around them. These seem to be an interlobular portion of the moraine between the broad valley to the south and a narrower valley coming in from the north along their east side, or else a local development of a later moraine not usually appearing, possibly an earlier portion of the second moraine.

Again, beginning near the southeast corner of T. 96, R. 57, a high, sharp, continuous ridge extends in a nearly direct line to sec. 12, T. 94, R. 56, where it quite abruptly declines in height, apparently having been washed away by water from the west. Through this range is an interesting gap through which Beaver Creek crosses it toward the east,

upon sec. 28, T. 95, R. 56. South of this is a conspicuous peak, locally known as Mount Pisgah. An interesting drainage channel at high level crosses the moraine north of the gap on the west lines of secs. 16 and 21, T. 95, R. 66. A conspicuous view of this portion of the moraine from the inside is given in Pl. V, and from the outside in fig. 9. Another drainage channel at higher level runs south obliquely across it along the west line of sec. 16, T. 95, R. 56.

A few morainic points in a ridge running east-west, northeast of Lakeport, suggests the idea that the broad gap south of Lesterville may at one time have been occupied by a small lobe from the ice sheet west. The highlands west of Yankton descend in a long, gentle slope from the vicinity of Lakeport to Yankton. This slope is traversed by valleys extending south of east which bear traces of running water. There are gravelly knolls and terraces, especially toward the foot of the slope. From the gap east of Lesterville extends a broad valley, running southeast. Just southwest of James Ridge this also opens

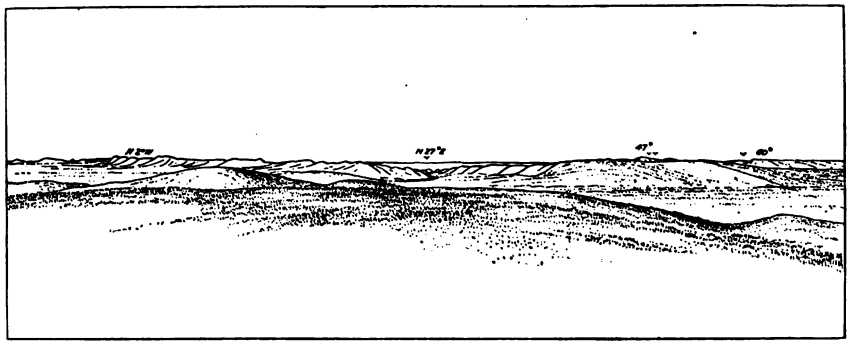
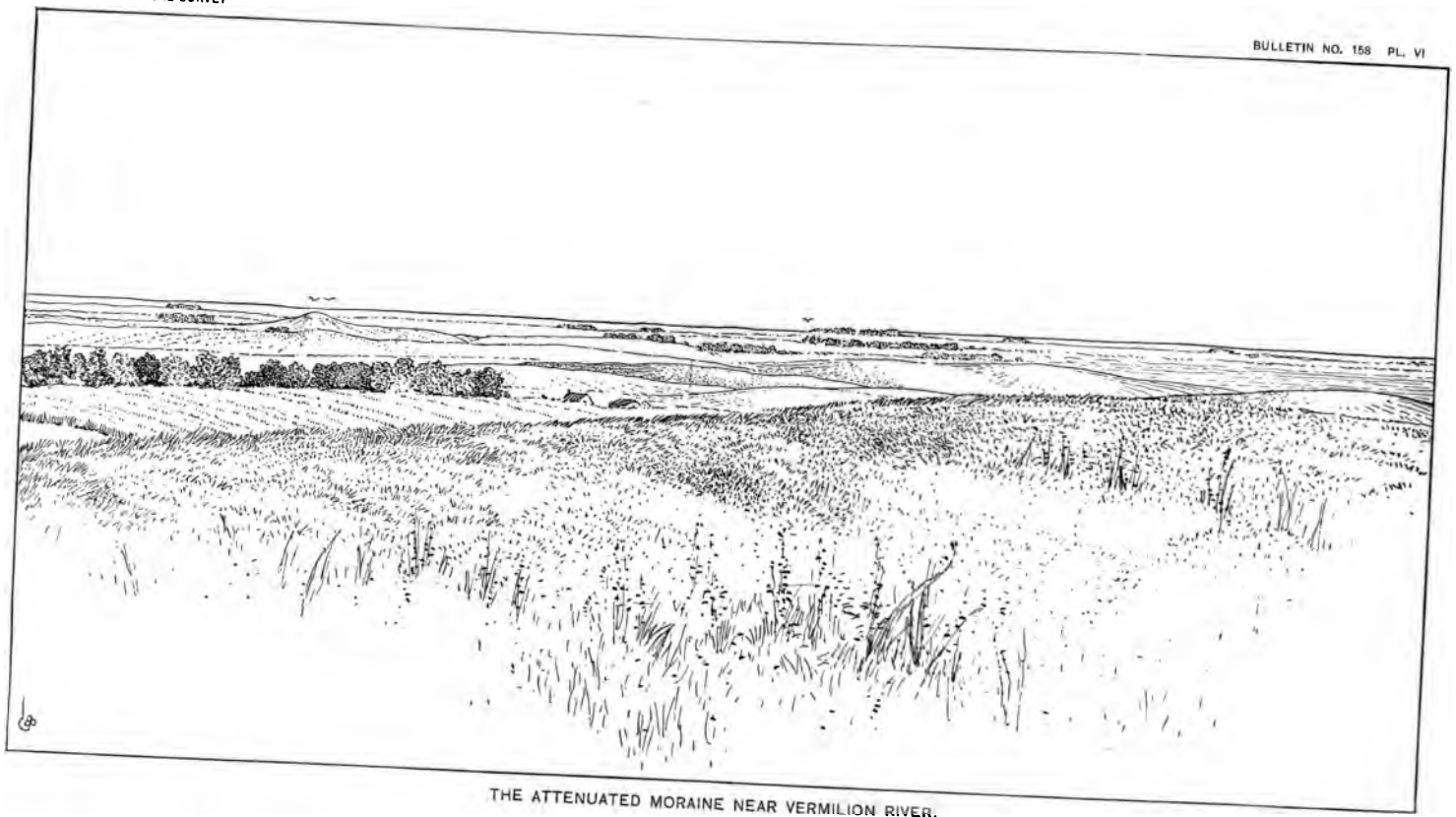


FIG. 9.—James Ridge, from the west. v Beaver Creek. vv Mount Pisgah.

toward the southeast upon a broad gravelly terrace, through which Beaver Creek in its lower portion has excavated a deep valley. James Ridge in its northern half seems to have been a narrow interlobular portion of the moraine. A lower bowldery ridge, somewhat detached, skirts its northern end much as in the case of the Choteau Creek Hills.

From a consideration of the topography of the gorge-like character of the trough of the Missouri from Bonhomme to Yankton, of the occurrence of blowing wells near Utica, and of the finding of fragments of quartzite like that of the Bijou Hills at the south end of James Ridge, it seems probable that before the advent of the glacier the Missouri, or rather the Niobrara, flowed northeast from Springfield and thence eastward north of Lakeport and Yankton to join the main river northwest of the latter place.

Extending along the east side of James Ridge, separated from it on the south by Beaver Creek, and turning east from the southern end of the higher part of James Ridge, is a morainic ridge, at one time thought to be a part of the outer moraine, but a more satisfactory



THE ATTENUATED MORAINE NEAR VERMILION RIVER.

v Missouri River. v v Spirit Mound.

naturally narrow valley, bounded by chalk cliffs rising from 50 to 100 feet above the water. Turkey Ridge is about 24 miles long and from 5 to 7 miles wide. Its surface is not very rough. Most of it is easily tilled, though in some places it is very stony. The prevailing stone is red quartzite. Its highest point is about 1,750 feet above tide, on sec. 5, T. 97, R. 55. From that place it declines quite regularly to about 1,400 feet for 2 or 3 miles west of Wakonda. A plan of it is given in Pl. VII; see also sections E–F and I–K with the general map (Pl. I). This is derived from the topographical survey of the United States Geological Survey made in 1896. In the later stages of the occupation of the moraine, as the ice thinned, the internal drainage ceased and the Vermilion lobe discharged along the line beginning in the eastern part of T. 97, R. 59, and extending to 2 miles west of Viborg, passing through the west side of T. 92, R. 52, thence nearly due south to sec. 9, T. 94, R. 52, thence southeast to the Vermilion River, passing just west of Spirit Mound.

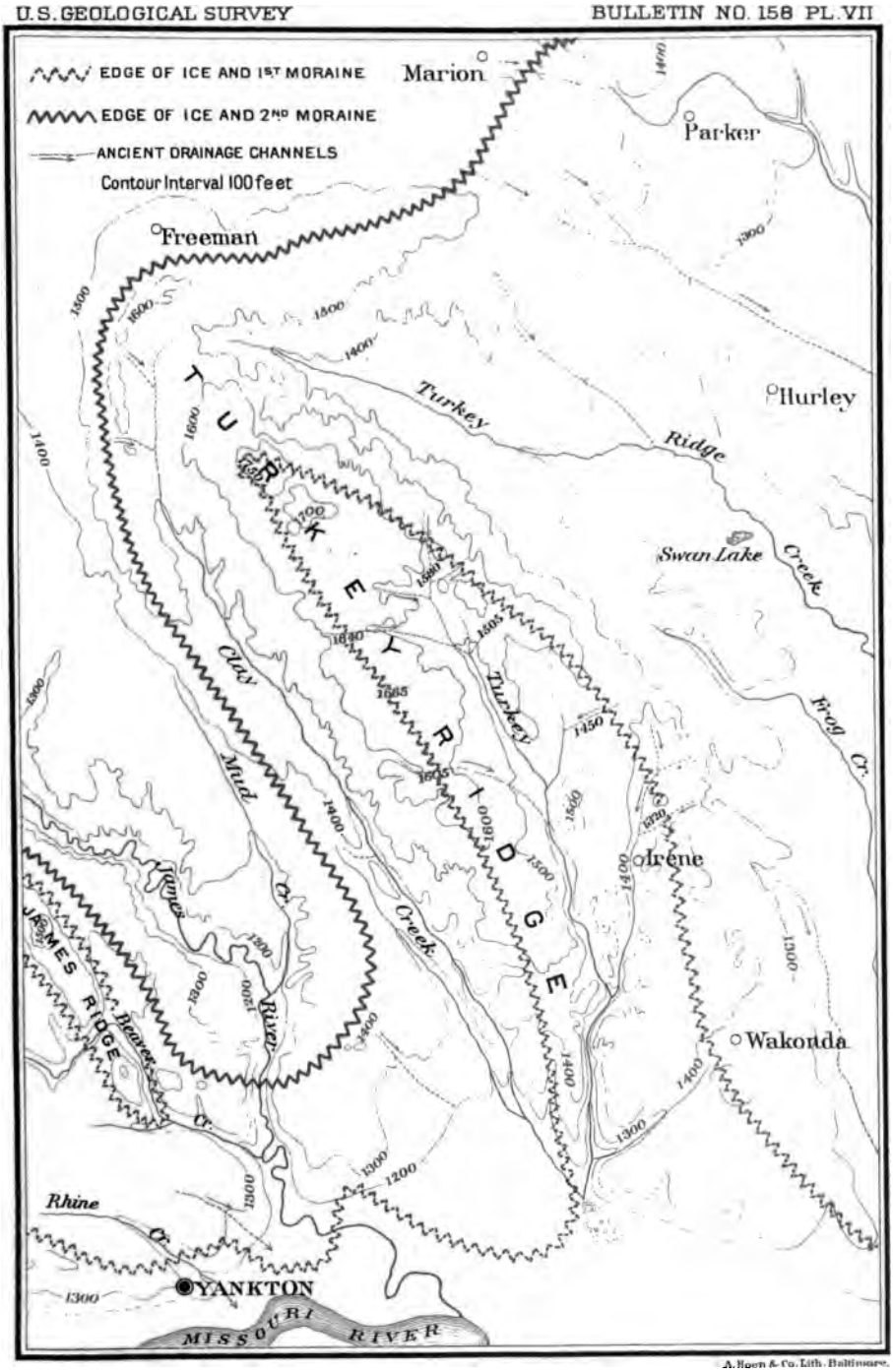
VERMILION GAP.

From this point there is a gap in the moraine about 8 miles in width. It is occupied by the very level plain along the Vermilion River. This plain extends southward and ends as a high terrace, the southern end of which extends from the mouth of the Vermilion nearly due east to the Big Sioux. It rises about 100 feet above the Missouri. This terrace, as exposed by cuts in the vicinity of Vermilion, is composed of blue bowlder clay below, containing pockets of sand, and passing above into yellow pebble clay, and this is capped in places with a silt indistinguishable from loess. The surface of this terrace frequently exhibits basins similar to those found upon till; and from the relation of the terrace to the moraine it was probably occupied by a narrow tongue of ice running down the pre-Glacial Vermilion Valley into the Missouri.

FROM BRULE CREEK TO CANTON.

Along the west bank of Brule Creek, as far south as sec. 13, T. 92, R. 50, and still more prominent in the northwest corner of T. 93, R. 50, and the southwest corner of the township north, the moraine appears in a few scattered knobs of drift. Between these hills are evidently overflow channels from the plain northeast to the valley of Brule Creek. Some of their outlets are partially occupied by small lakes. These hills toward the north become connected into a broad swell composed of bowlder clay, which rises and broadens toward the north and extends past Beresford, situated upon its summit, thence north and northeast to the middle of the southern line of T. 98, R. 49, where it terminates abruptly, overlooking a broad valley, which slopes from the plain northwest down into the valley of the Big Sioux at Canton.

This portion of the moraine is not traversed by overflow channels of any considerable size, at least none have eroded the moraine very deeply.



MAP OF TURKEY RIDGE, BY J. E. TODD, 1898.

There are, moreover, few knobs or morainic points exhibited by this portion of the moraine. It forms the western edge of a highland region occupying the whole area between it and the Big Sioux River on the east. This highland region is uniformly covered, especially upon the hilltops, with loess, some of the points of it rising higher than the nearer portions of the moraine. Branches of Brule Creek and the Big Sioux have eroded the whole surface of this highland so that the height of the hills above the valleys is often more than 150 feet. That there was more or less overflow across the moraine is indicated by numerous broad, marshy valleys extending from the summit of the moraine southward into Brule Creek. This is especially true in the vicinity of Beresford and south of Canton. At the northern end of the highland region it rises about 300 feet above the Big Sioux, and the valleys heading near the moraine are narrower and deeper than those farther south.

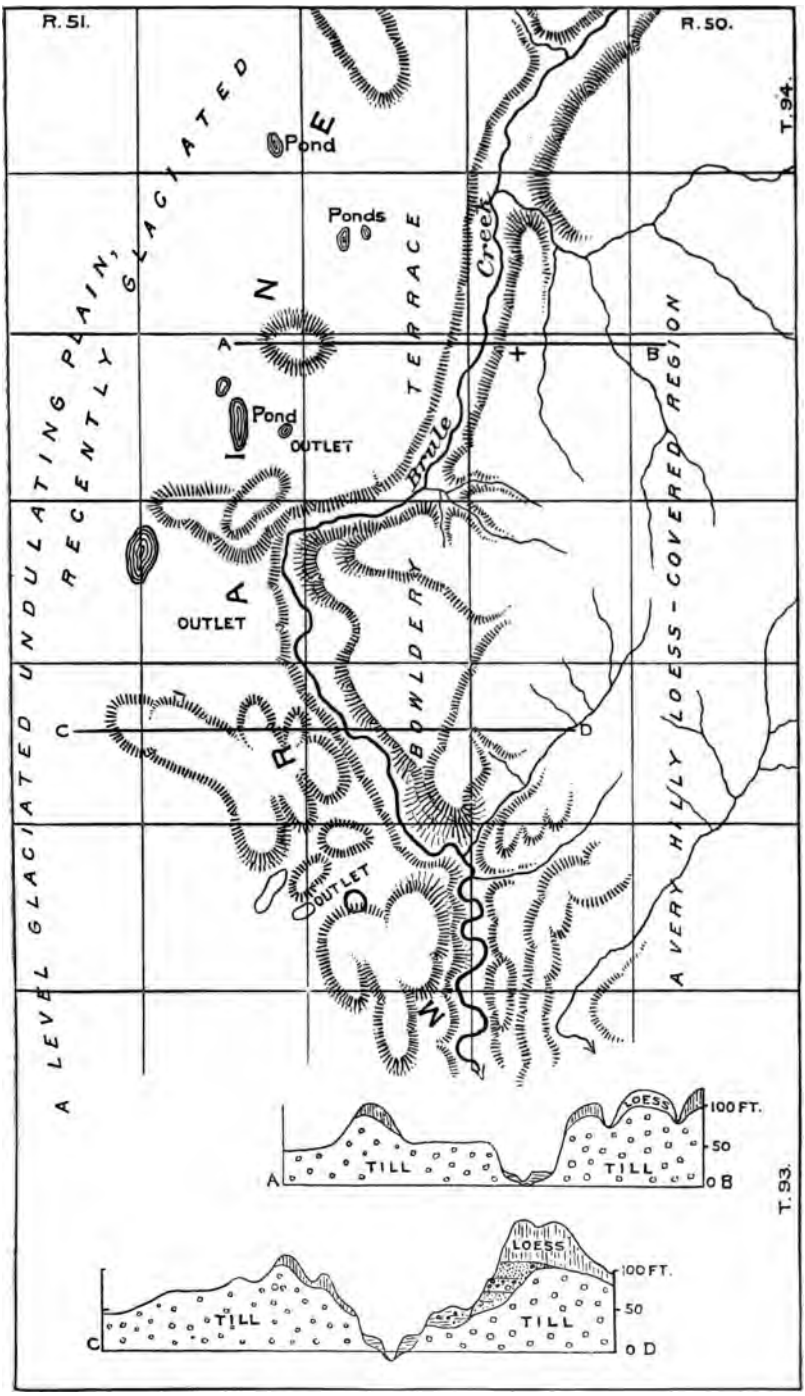
One of the most instructive portions of the moraine in this region, and indeed in any region, is that lying along the west side of Brule Creek, through Ts. 94, 93, and 92, R. 50. In the northern part of the first mentioned the moraine has the same features as near Beresford, and passes gradually into the eroded highland region farther east. This ends in sec. 17, and farther south there is an alternation of drainage channels with bowlder knobs. This is represented in part in Pl. VIII. These outlet channels are upon the same level as the plain farther west, and from 30 to 50 feet above the water in Brule Creek. In some of the wider it would seem that the ice occupied the channel and left ponds and bowlders over the surface, as in the common glaciated areas. These knobs rise over 100 and 150 feet above the creek and from 60 to 70 feet above the surrounding plain. The channels are not all upon the same level, but are deeper toward the south. Their eastern surface is mantled with loam, indistinguishable from loess. It has not been found, however, more than 5 or 6 feet deep, and it is not difficult to account for the numerous cases by eolian action in time of northwest winds. East of the creek the till rises to about the same level as that which forms the body of these knobs. At several points along the creek, and 50 to 70 feet above it, there are thick deposits of sand and gravel directly underlying the loess, which is much deeper upon the eastern side of the creek. The relation is shown in one of the sections in Pl. VIII. Between secs. 8 and 9, T. 93, R. 50, the stream flows through a narrow gorge which seems to owe its character partly to the slipping masses of loess. From that point to secs. 24 and 25, T. 92, R. 50, there is no morainic material west of the creek, but at the latter point the hills again appear very distinctly on the west side of the creek. It is evident that Brule Creek began its course when the ice occupied the Vermilion Valley as far south as the Missouri, and that the ice rose nearly or quite as high as the general level of the loess farther east. The question presents itself whether the water during the early occupation of the moraine flowed as high as that level, so as to dis-

charge eastward over the loess of Brule Creek. There are some things, both at this point and in the vicinity of Fairview, which seem to indicate this condition. For example, the width of Brule Creek between secs. 8 and 9, T. 93, R. 50, seems too narrow for the width of the valley farther north and the numerous outlets leading to it. Again, south of Beresford, but more north of that place, while there are no prominent drainage channels, there are shallow ones which cross the moraine at a high altitude, some of them as high as and even higher than the level of the loess farther east. Moreover, northeast of Beresford there is a peculiar mingling of bowlder knolls and loess, as if the loess portion of it had been deposited in the valleys of the till.

BIG SIOUX GAP.

From the northern end of the highland south of Canton to the highland south of Sioux Falls, on sec. 29, T. 101, R. 48, we have again a depauperated portion of the moraine. It is only represented by a few isolated hills lying along the west bank of the Big Sioux. They present at first sight the peculiar phenomenon of detached portions of the table-lands east of the Big Sioux. They rise to nearly the same height and are about 150 feet above the plain to the west. The first of these is about 1 mile northeast of Canton—a low hill composed largely of gravel, rising about 150 feet above the river. The second is a much more important hill, occupying much of sec. 6, T. 98, R. 48; the third a hill occupying sec. 20, T. 99, R. 48; the fourth, in or near sec. 15, T. 100, R. 49. These hills are composed of drift, and when of any size show basins indicating their morainic character. Between the highland south of Canton and the hill northeast there is a broad incline from the plain on the northwest to the level of the Big Sioux. Upon this slope two or three terraces may be traced. The plain on the northwest rises about 130 feet above the river. Continuous with the higher of these terraces, which is the more stony, is a long bowldery terrace extending down the Big Sioux, and gradually declining in altitude to the valley of the Rock River. It reminds one of the terrace on the Missouri extending from the mouth of Pratt Creek southward. The valley of the Big Sioux here is narrower, apparently not more than half the width of the Rock River. This is especially true in the vicinity of Fairview. This suggests its recent excavation, perhaps during the later occupation of the principal moraine.

North of Canton the plain to the west comes up quite sharply to the valley of the river, leaving a terrace-like edge, except in the vicinity of small streams emptying into the Sioux. East of the Sioux, as before intimated, the general level is from 200 to 250 feet above the river. No trace of Cretaceous clays was clearly noted along the Big Sioux above Canton till the northwest corner of Iowa was nearly reached. It is probable that they rise from 25 to 50 feet above the present stream. Northwest of Canton the chalkstone of the Niobrara group occupies



DETAILS OF THE MORAINE IN UNION COUNTY, SOUTH DAKOTA.

the bank of a small stream at a height of nearly 100 feet above the Big Sioux. There seems to be no evidence that any portion of the east bluffs of the Big Sioux represents any part of the moraine.

FROM THE BIG SIOUX TO VERMILION POINT.

Beginning on the west side of the Big Sioux, about a mile north of the northern boundary of Iowa, a high massive ridge begins to extend westward and southwestward around the Great Bend of the Big Sioux, and continues its westerly course to near the southwest corner of T. 101, R. 51. Thence curving northward, it crosses the Chicago, St. Paul, Minneapolis and Omaha Railway about 4 miles east of Montrose, then closely follows the east side of the East Vermilion, crossing the Chicago, Milwaukee and St. Paul Railway west of Winfred, and continues in that direction to a point about 12 miles northwest of Mad-

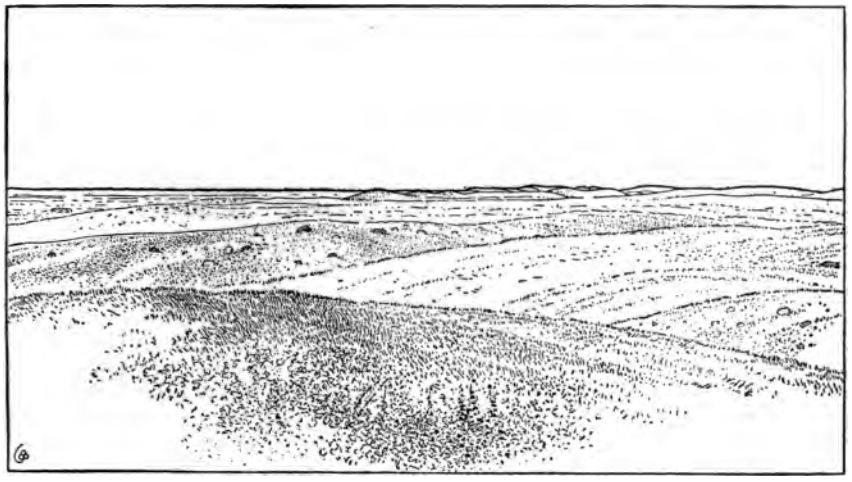


FIG. 10.—Inner slope of the moraine south of Wall Lake.

ison. The line indicated marks its inner slope. Its outer slope is less distinctly marked, being irregular, but usually with slight descent toward the north and east. Of the portion just traced, that immediately south of the bend of the Big Sioux is the lowest, rising only about 120 feet above the water in the river. It bears traces of several drainage channels, as though considerable water had been discharged northward from this point. About 3 miles southeast of Sioux Falls is the highest point east of the bend. It rises about 265 feet above the river to the east, or 165 feet above the Chicago, Milwaukee, St. Paul and Omaha station at Sioux Falls. In this elevated portion the moraine has been least modified, and therefore shows its usual characteristics—stony knobs and ridges, with ponds. The moraine has been crossed in the vicinity of Wall Lake, east of Montrose and east of Winfred. At the first of these points its height is 175 feet above the plain to the south-

west. East of Montrose and east of Winfred the altitude is about 200 feet. At all of these points the inner surface of the moraine is very stony and unusually marked with knobs, which are more numerous upon the inner slope than upon the summit of the moraine (fig. 10).

As one looks from the moraine toward the outside the view is like that of a plain, with numerous ponds in places. Elsewhere these ponds seem to have been drained by shallow channels of erosion, connecting with Skunk Creek. These channels are not uniformly from the inner surface of the moraine outward, but often parallel to it, or even occasionally flowing toward it. In these shallow valleys are sometimes found systems of elongated, sharp, stony ridges. One example was noted along a branch of Skunk Creek in the southwest corner of T. 101, R. 50. Another and more extensive system is found about 5 miles from Montrose, leading from a shallow gap in the moraine and extending to a branch of Skunk Creek. (Pls. IX and X.) A fuller description will be given in a later chapter.

The outer surface of the moraine gently declines to the surface of an undulating plain traversed by channels too large for their present streams. This portion of the moraine has no deep outlet channels traversing it. Its summit is not very rough, but from Hartford to Russell it is from 8 to 10 miles wide, and its outer slope abounds in prominent stony knobs and ridges interspersed with lakes.

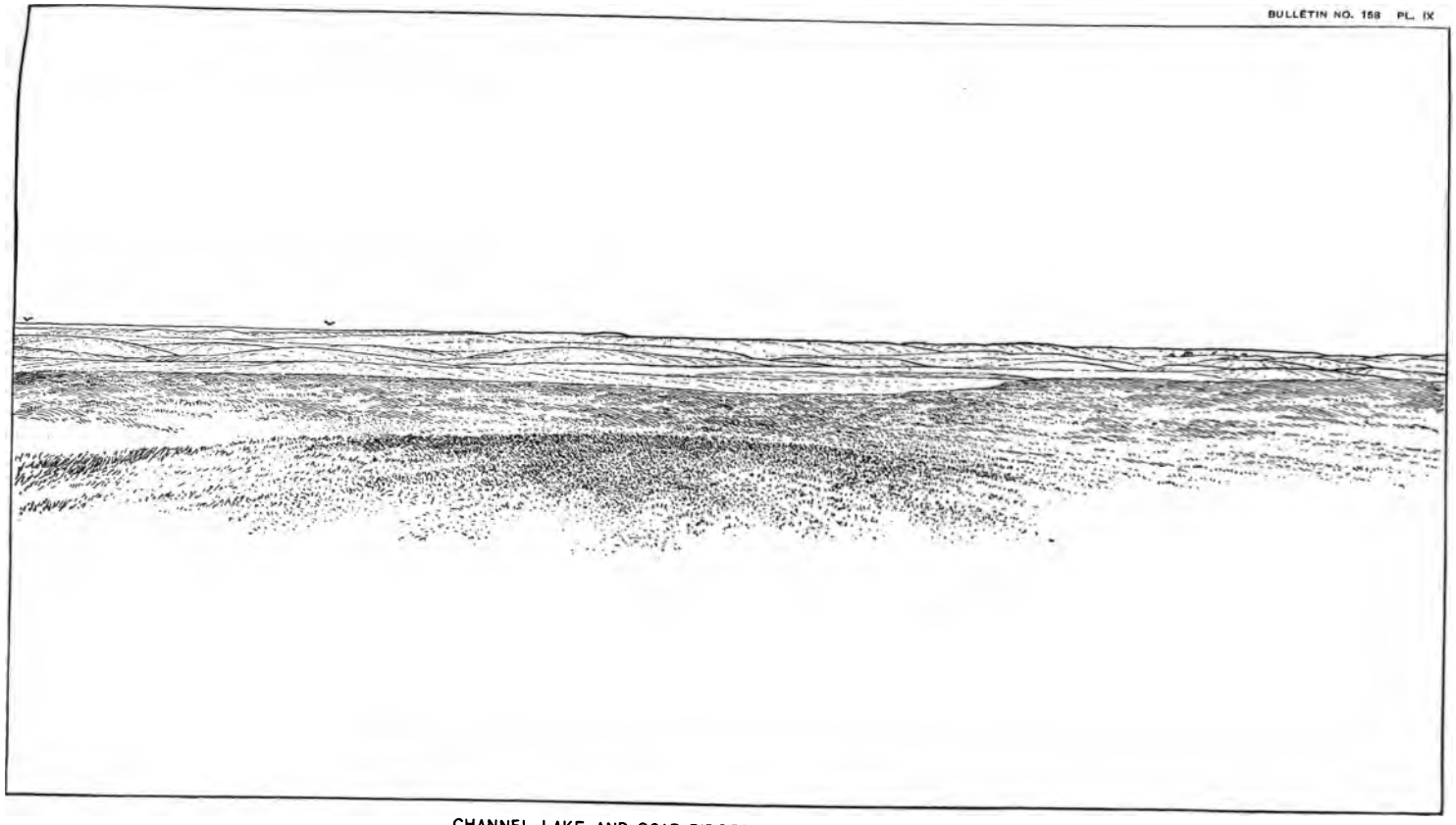
Vermilion Point is the termination of Vermilion Ridge, where it gradually subsides into the undulating plain on the north. Instead of resting upon the edge of an elevated terrace like Turtle Point, it lies on a plain running eastward. For this reason it is not nearly so prominent.

This completes the tracing of the outer moraine in the region chosen for consideration.

From Vermilion Point the moraine turns sharply east and northeast, and after crossing Battle Creek about 6 miles south of Madison, it quickly turns to a northerly course and passes 4 or 5 miles west of Volga. The southern side of this loop is slightly developed, or much eroded, but the eastern is very rough. It does not present the appearance of a broad swell, as in much of its course, but a disorderly mingling of frowning knobs and ridges, with narrow and broad channels which are frequently studded with lakes. The outer boundary of the moraine in this portion is marked by the northeasterly portion of Battle Creek and the flood plain of the Big Sioux farther north.

GENERAL CHARACTERISTICS OF THE MORAINE.

The term *moraine*, although already frequently used in this paper, has not been clearly defined. It is a word introduced from the French, but may be traced with the Italian *mora*, a heap of stone, and the Spanish *moron*, hill or hillock, to the Latin *murus*, which not only has the primary meaning of "wall," but also "dam," "edge of a pot," etc.



CHANNEL, LAKE, AND OSAR RIDGES NORTHEAST OF MONTROSE.

v v Plain inside or west of the moraine.

Both wall and rim of a pot are instructive comparisons in forming an idea of moraine as used in this paper.

Moraine, as commonly used, includes all the débris, bowlders, pebbles, sand, and clay which is transported and deposited in various situations by a glacier. The moraine of which we speak in these pages is always the system of hills believed to have been heaped up around the edge of an ice sheet. Such hills are recognized as belonging to the moraine more by their relative position than by any one character which they bear individually. Each one is usually circular or lengthened parallel with the course of the system, abounds in bowlders, and has quite abrupt sides, but none of these characters are always found.

As a system the moraine usually presents these stony, knobby hills, mingled confusedly with circular and winding basins, which often contain water, but sometimes both basins and hills are very faintly developed, so that the whole constitutes a broad swell. The moraine is traversed here and there by transverse valleys, by which water escapes from the ice sheet. These may be of trifling size or many rods in width and cutting down through the whole height of the moraine.

The height of the moraine at any point is due, first, to the relative elevation of the pre-Glacial surface; second, to the amount of material pushed forward, which itself depends upon the pushing power of the glacier and the time its edge remains stationary; third, to the amount of material washed away; and, fourth, to the consistency of the material. Excess of clay or sand tends to produce a low and even moraine, while excess of stony material is favorable to the formation of a high and rugged moraine.

STRUCTURE AND POSITION.

A cross section of the moraine where least modified is a broad, low scalene triangle, the shorter side being inside, the longer, considerably

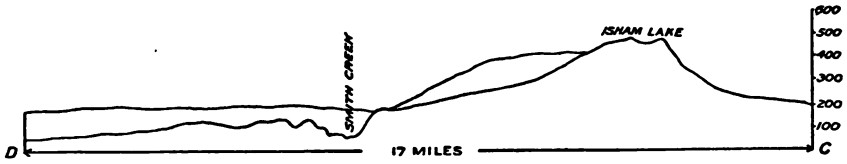


FIG. 11.—Section of southwest Wessingtons.

less abrupt, being outside. Much of the moraine, however, is so modified that these features do not appear. Portions best illustrating the character mentioned are found where the moraine is neither doubled upon itself nor closely adjacent to an important drainage channel, as, for example, the southwest Wessington Hills (fig. 11), the portion between Lake Andes and Choteau Creek, and the portion between Vermilion River and Canton, and again from Sioux Falls to Winfred. As has been already intimated, the pre-Glacial topography is believed

to have had great influence upon both the course and the character of the moraine. For example, the locations of Turtle Ridge, Choteau Creek Hills, and Turkey Ridge are doubtless due to the positions of high pre-Glacial buttes. The position of Vermilion Ridge seems rather determined by the distance which the ice sheet could force itself up an inclined plane. The subordinate lobes, as in the case of the Dakota lobe itself, were primarily determined by the existence of valleys down or up which the ice pushed its way.

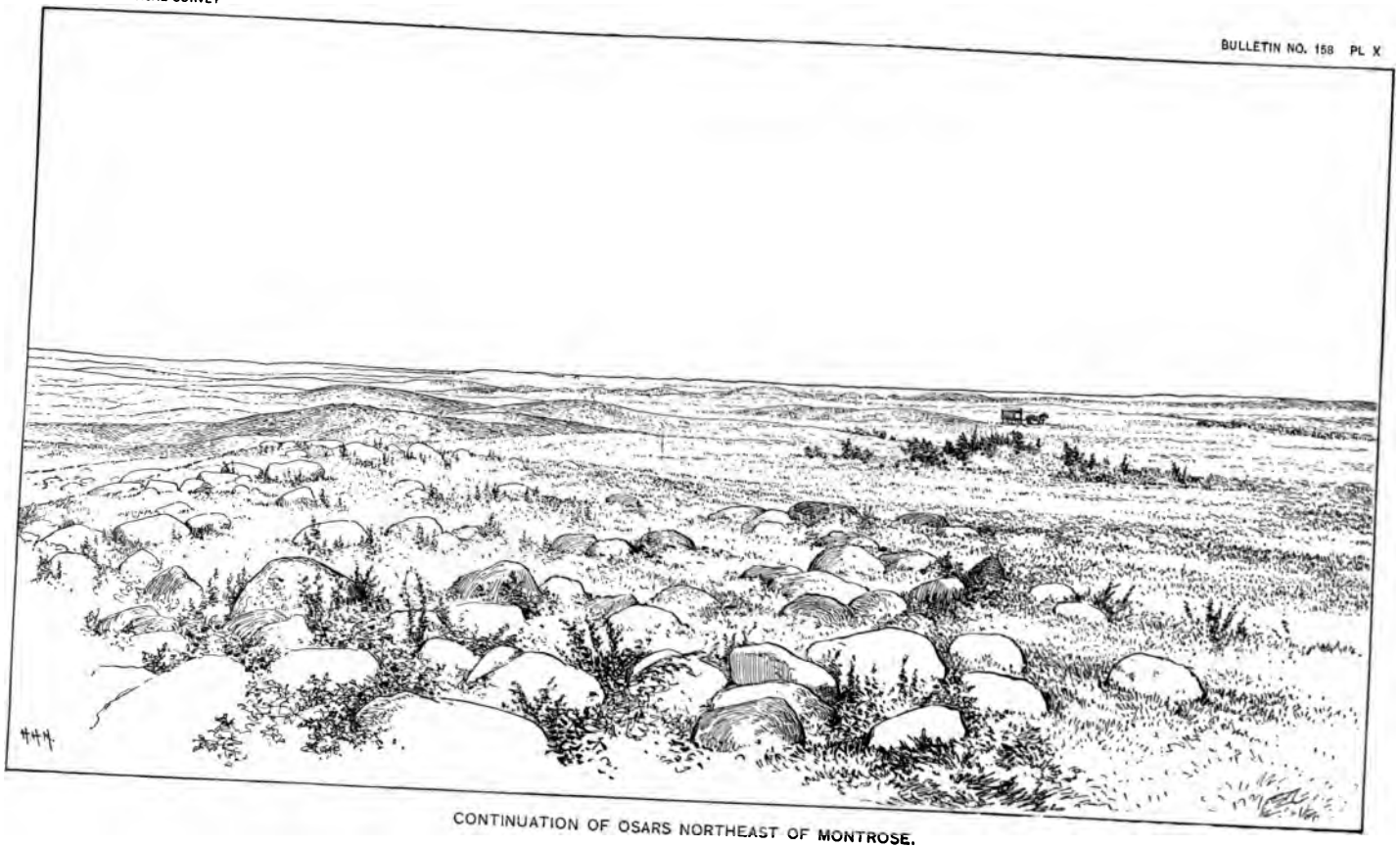
HEIGHT.

The moraine has an elevation, above the plain inside, of from 50 to 400 feet. Its average height is about 100 feet. The extreme elevations, as, for example, in Turtle Ridge, are in localities nearer the center of the ice sheet, where we may suppose its thickness was greater and its transporting action more pronounced. The lowest portions are found apparently either where the ice sheet extended into ponded waters or where it was acted upon by floods of water coincident with or subsequent to its formation. An example of the first case is found north and south of the Bijou Hills. An example of the second is found in the lower portions of the James and Vermilion valleys. It seems not improbable that some of the less developed portions of the moraine are to be accounted for by their distance from the source of material and their transient occupation by the ice sheet. For example, the ice can hardly be conceived as occupying the moraine in the vicinity of Kimball as long as it did in the vicinity of Wessington Springs or of Lake Andes. It seems not improbable, also, that, other things being equal, if the drainage of an ice lobe is lateral an excess of material would be found near the termination of a glacier rather than in its lateral portions. This may explain the height of the moraine in the vicinity of Lake Andes.

The outer or principal moraine, in general, appears to increase in height toward the north, and still more toward the west. Both of these features will be seen from the following table:

Table showing heights of outer moraine.

Locality.	Elevation above—			Highest rocks near by.
	River outside.	Plain inside.	Sea.	
West of Russell	330	200	1,825	
Northeast of Montrose	.....	200	1,740	
West of Hartford	289	200	1,692	
South of Wall Lake	247	175	1,650	
South of Sioux Falls	130	125	1,519–1,525	
Southeast of Sioux Falls	265	155	1,555	120
Southwest corner T. 99, R. 48	200	110	1,525	



CONTINUATION OF OSARS NORTHEAST OF MONTROSE.

Table showing heights of outer moraine—Continued.

Locality.	Elevation above—			Highest rocks near by.
	River outside.	Plain inside.	Sea.	
South of Canton	310	130	1,550	
Beresford	349	225	1,505	
Sec. 31, T. 94, R. 53	100	75	1,325	
Spirit Mound	215	90	1,361	18
Sec. 31, T. 94, R. 53	275	150	1,421	
Sec. 5, T. 97, R. 55	.....	.....	1,740	
Sec. 28, T. 95, R. 54	260	150	1,450	100
Sec. 7, T. 94, R. 55	250	100	1,440	
Mount Pisgah, (sec. 34, T. 95, R. 56)	290	135	1,475	
Northwest of Lesterville	.....	65	*a* 1,400	
Lakeport	310	.....	*a* 1,500	120
Sec. 3, T. 92, R. 61	400	160	1,615	
Sec. 4, T. 95, R. 61	160	120	1,745	
North end of Choteau Creek Hills	.....	260	1,800	150(?)
East center T. 95, R. 62	100	250	1,805	
Prospect Point (sec. 8, T. 97, R. 61)	.....	.....	1,645	
Northeast corner T. 94, R. 63	400	200	1,620	
South center T. 94, R. 62	610	.....	1,850	200
South of Lake Andes	605	390	1,845	
Sec. 6, T. 96, R. 66	450	260	.....	55
Sec. 24, T. 97, R. 68	575	54	1,865	50
Sec. 28, T. 98, R. 68	697	175	1,986	
Southwest end of East Bijou	800	300	2,090	
East end of East Bijou	.....	275	1,975	
North of end of East Bijou 2 miles	.....	75	*a* 1,775	
Hills near Kimball	.....	50	1,820	
Southwest Wessingtons near Ishams Lake	.....	300	.....	
Turtle Point	.....	475	1,954	100
Sec. 27, T. 108, R. 66	.....	200	1,785	
Sec. 3, T. 107, R. 69	215	110	1,765	

a Estimated.

STONINESS OF THE MORAINE AND DISTRIBUTION OF BOWLDERS.

The stoniness of the moraine seems to bear a direct relation to the action of water upon it. Where there are traces of torrential wash in the configuration of the country there is usually an increase in the number of bowlders; for example, in the internal drainage of Turtle Ridge bowlders abound upon the abrupt sides of the channels. And yet this was evidently only one influence among several. The occur-

rence of bowlders in patches or nests, upon the moraine as well as upon the till, is probably due to some obscure segregating action of the glacier or of glacial streams.

The number of bowlders in general in the Dakota moraine is much less than in moraines farther east, as, for instance, in Wisconsin. This is to be explained largely by the absence of bowlder-forming rocks in the region. The glaciers over the whole Dakota lobe, with the exception of a few isolated square miles of Archean rocks, rested upon clay which was evidently easily eroded both by water and by ice. As has been already stated, the harder strata at the advent of the ice were, as a rule, found capping a few buttes. These buttes, in most cases, seem to have withstood the ice, and so their capping was not transported to any great distance.

Bowlders of crystalline rocks, granite, greenstone, quartzites of several sorts, and of a very fine-grained, compact white limestone from the upper Silurian beds, occur everywhere, with little variation in their relative prominence. Some of the variations noticed in the character and distribution of bowlders are as follows: Flesh-colored, fine-grained granite, black slate, and white and dark quartzites abound more along the western side of the Dakota lobe. The white and the yellow Silurian limestones were noticed in unusual size and profusion in Lake Andes Outlet and about the mouth of Choteau Creek, especially to the west of that stream. Bowlders from 8 to 10 feet long and from 2 to 3 feet thick are not uncommon, while smaller ones are much more frequent. Their abundance so impressed me that in several clusters and heaps I counted them. In one, 16 out of 22 were limestone; in another, 8 out of 16; in another, 40 out of 48. Several others showed more than half limestone. The clusters counted were all on the lower bowldery terrace.

There are several kinds of rocks found in southeastern South Dakota which are adapted to form erratics. One is a siliceous rock of Tertiary origin resembling buhrstone, of fine texture, yellowish color, and usually marked with the stems of plants. This has been noticed apparently near position a little south of the Northern Pacific Railway, and occasional bowlders, not often more than 6 inches in diameter, are distributed to all portions outside of the moraine, specimens being found, though never in considerable numbers, as far south and east as Page County, Iowa. A second rock is the greenish quartzite capping the buttes of the Bijou Hills system. This stone seems not to retain its hardness when exposed to the action of alkaline waters, for bowlders of this rock are rarely found far from their original position without showing much disintegration. The next two, from the Cretaceous, furnish bowlders, but they last for only a short time and are found rarely at much distance from their original beds. They are the "chalkstone" and the Dakota sandstone. Under the influence of moisture and shearing stress one quickly changes to clay and the other to sand. Fossils from

the one and pebbles from the other are not infrequently found. The largest bowlders from the Cretaceous, though rarely over a foot in diameter, are fragments of large bluish limestone concretions from the Benton, and usually show a septarian structure; they are not common, but seem quite durable. Interesting erratics, but rarely more than 4 inches in width, are derived from the Pierre and Benton. They are fragments of clay-ironstone concretions, which on weathering become hollow pebbles of limonite. The last is by far the most important. It is the well-known quartzite which exists in extensive ledges through southern Minnesota and westward as far as the vicinity of Mitchell. Its structure is favorable to the formation of bowlders, being naturally divided into blocks by numerous joints and seams of stratification. Furthermore, its indestructibility preserves the bowlders when passing through the ordeal of glacial and glacionatant action. Red quartzite bowlders are rarely over 5 feet in length. The most western point where this rock was exposed to the abrasion of the ice is at Rockport. Another point farther west is found on Enemy Creek, in sec. 20, T. 102, R. 59, but from its lower position seems never to have been eroded by the action of the ice. The most western point in the moraine and the deposits outside at which red quartzite bowlders have been found is in a line nearly due south of Rockport, on How Creek, in northern Nebraska. It is not unlikely that an extended search in the Choteau Creek Hills may discover them there, but as yet none have been observed. From this point they increase rapidly in numbers toward the east. This distribution corresponds with the direction of the glacial scratches at Rockport and vicinity, which is southeast.

Another interesting point in the distribution of the red quartzite bowlders is that they are very abundant—70 to 90 per cent of all erratics—in the north end of Turtle Ridge, southwest of Turtle Ridge Creek and east of Clay Creek, but outside (north and west) of those streams they are rare. This is so noticeable, that it has attracted the attention of the residents of the region. This corresponds with the distinction between the first and second moraines.

CHAPTER III.

THE DRIFT REGION OUTSIDE OF THE OUTER MORAINE.

The drift, by which we mean any deposit, whether bowlder-clay, sand, or gravel, containing erratics which show marks of ice action, extends for greatly varying distances outside of the moraine. As already stated, the erratics are mainly from the Archean and Silurian rocks. The region under consideration is naturally separated into the following divisions, which may be designated according to the portions of the moraine corresponding to their inner boundary.

What we shall, for convenience, style the Red Lake region, includes all territory lying outside of the moraine from Turtle Point and the moraine west to the vicinity of Pratt Creek, embracing—

The Ponca reach, extending from the mouth of Pratt Creek to the mouth of the Niobrara.

The loess region, extending on its northwestern border from the mouth of the Niobrara to Sioux Falls.

The Coteau des Prairies region, extending from Sioux Falls to Vermilion Point and beyond.

In each case the outer limit, as before stated, is the limit of the drift. Each region presents characters peculiar to itself. The first occupies an extensive external angle of the moraine and presents the peculiarity of driftless areas rising as islands above the sheet of investing drift. The second is long and quite narrow, being confined almost wholly to the present gorge of the Missouri. The third is covered with a continuous sheet of drift, and that again with a blanket of loam or loess. The fourth, like the first, occupies an extensive angle of the Missouri, but presents no driftless islands and is only partially covered with the loess.

RED LAKE REGION.

Topographically this region consists of a broad, basin-like widening of the more elevated or superficial portion of the valley of the Missouri, from the vicinity of the Great Bend to the vicinity of the Bijou Hills. It may be compared to a great lake bed in which wide, shallow channels have been eroded, and then at a later stage some of the principal ones have been narrowed and cut down to thrice their original depth.

The region is bounded on the north and east by the moraine. On the west its boundary may be given provisionally as follows: From the Missouri above the Great Bend along the west side of Medicine Creek

to the vicinity of Medicine Butte; thence past Red Butte south across White River; thence curving southeast to Waterholes Creek, 5 or 6 miles above its mouth; thence along the eastern side of its abrupt valley to the Missouri, which it closely follows down to the mouth of Snake Creek. This boundary is mainly determined by the distribution of bowlders, which are sparsely scattered over the older deposits of the country. The underlying rocks of the region are Pierre clays, which were evidently much eroded before the deposition of the drift. The Tertiary also is represented by quartzite, gravels, and probably some clays, capping the buttes along the southern and western border.

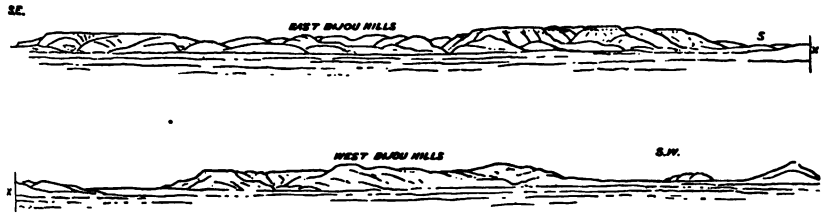


FIG. 12.—Bijou Hills, from the north.

The bottom of the pre-Glacial basin, as indicated by the course of the streams as well as by direct observation, was in the vicinity of Chamberlain. Around the edge of the basin to the west and south are isolated buttes capped with a greenish Tertiary quartzite. A range of these begins with the Bijou Hills and extends in a nearly continuous range westward. (See figs. 12 and 13.) Similar buttes are found southwest of the Great Bend, one of the more conspicuous being Medicine Butte, about 16 miles west-northwest from Chamberlain.

The drift which covers this region varies in thickness from 20 to 80 feet along the eastern side to merely scattered bowlders, as is usually

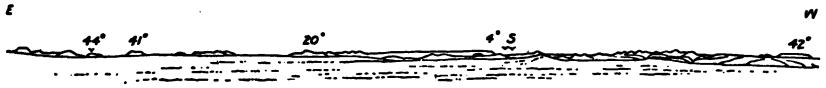


FIG. 13.—Buttes south of White River, from the north. v West end of Bijous. vv Gap of Waterholes Creek.

the case, west of the Missouri. These become fewer and smaller to a scarcely determinable edge. On the east side of the Missouri, between it and the moraine, is a nearly continuous sheet of till, which, as elsewhere, is yellowish above and reddish or bluish below. The surface of this till is unlike that which is found inside of the moraine in that it combines the usual features of erosive topography with faint traces of such basins as are found within the moraine. The average height of hills above minor valleys is from 30 to 50 feet. The elevation of the broad swells or uplands above the principal valleys is from 125 to 200 feet. Basins are rarely over 5 feet in depth and an acre in area. Moreover, many of these, by their position, suggest the idea that they are

due to the imperfect filling of old tributary valleys. They were noticed, especially along the northwest side of the Red Lake Valley, about 50 feet above its bottom. The accumulation of an indistinct terrace below that level may be conceived to have filled the side valleys at the mouth more than farther back. The surface is rarely too rough for tillage, except in the banks of present streams. The higher portions are covered, west and north of Red Lake, with 6 to 10 feet of yellow silt or loess. This hides bowlders, which are seldom seen except below 50 feet above the bottom of Red Lake Valley. In places there are traces of a terrace at about that height, as has been already stated, but bowlders are not confined to it, and are probably more noticeable below that level, because the loess has there been frequently removed. Everywhere there is a rich, black, loamy soil, except in basins and low flats, where "alkali" clay abounds.

To the general statement that the region between the Missouri and the moraine is covered with till, the following notable exceptions must be made: First, the region bounded on the north by a shallow valley running along the north line of Buffalo County from the Missouri to Boxelder Creek, thence along that stream on the east to its junction with Crow Creek, and thence by an undetermined line to a bend in the Missouri about 5 miles above Chamberlain. Over this region the drift is absent, except in the form of bowldery terraces along the principal streams, and elsewhere sparsely scattered bowlders, perhaps one to the square mile. The surface of this region presents gentle declivities, except close to larger streams, where the underlying clay has been excavated into yawning ravines. The deep unbroken valleys lie about 100 feet below the broad rounded swells which separate them. The soil on the upland is a fertile, black, loamy clay. The sides of ravines are barren. The highest portions above Crow Creek are about 1,770 feet above the sea, or 450 feet above the Missouri. The highest summit south of Crow Creek and one a few miles northwest of Chamberlain may be a few feet higher, but neither rises to the height of the till near Bijou Gap.

Another and more perfect exception is found in the western Bijou Hills, including the western end of the East Bijou, the West Bijou, the buttes which stand in the gorge of the Missouri, and the summit of a smaller hill northwest of Bijou Gap. Upon all these no drift, not even scattered bowlders or pebbles of drift origin, is found above the altitude of 1,885 feet, or 565 feet above the Missouri at Chamberlain.

The distribution of drift in the East Bijou is peculiar, and as it affords a contrast to the cases in hand, we will consider it more fully. The hill is a long, narrow butte, nearly 6 miles long and over a mile wide near its western end, and 300 feet in height. The eastern end is wrapped in a heavy covering of bowldery drift, as is all, except a sickle-shaped spur about a mile in length and nearly equal in height to the rest of the hill, which extends northwest from the body of the hill and

curves around toward the southwest. This spur, with a sharp southwest angle of the hill, incloses an amphitheater which opens to the southwest. The southwest angle of the hill is covered with bowlder clay upon its southern and western slopes to the depth of about 30 feet. The top of the northwest spur is wholly without drift, except on its outer slope. In the amphitheater bowlder clay rises to the 1,885-foot level in foothills which show a gentler slope than the hill itself. A conical hill lying a little detached from the north side of the hill is also driftless. The edge of the till on the flat summit of the hill ends in a slope to the northwest, its trend being northeast–southwest.

West of the Missouri only scattered bowlders are found remote from the immediate vicinity of the gorges of the Missouri and White rivers, except a gravel-topped plateau several miles in extent southwest of the mouth of White River and south of American Crow Creek, 3 or 4 miles from the Missouri. Masses of drift, both gravel and bowlders, are also found capping extensive terraces along both the Missouri and the White rivers from 200 to 250 feet above the present level. These will be more fully described in the chapter on terraces.

Along the south side of the old valley of White River, which is 2 miles in width, and in which the present gorge is excavated to the depth of 200 feet, extends a very conspicuous elevated plain covered with gravel, estimated to be 2 or 3 miles wide and extending along White River at least 5 miles. It is much eroded by ravines. Its pebbles are mostly of western origin, as is indicated by the great number of glassy, white, dark, and black quartz, and fragments of chalcedony seams. Granites and white limestone and other northern bowlders are prominent on the sides of the ravines and scattered less frequently on the level surface. This plain lies about 350 feet above White River. Along the southern side of this plain lies a low swell, about 20 feet in height, on which there is a great profusion of bowlders of all sorts; 28 granite bowlders from 1½ to 4 feet in diameter were counted in going up the ridge, one being 6 by 4 feet. A little south, and about 25 feet higher, blocks of Bijou quartzite are abundant, and Cretaceous clay occupies the eroded but gradually rising surface for 4 or 5 miles farther south. At that point a cluster of flat-topped hills rises about 75 feet above the surrounding plain and about 550 above the Missouri. They are considerably eroded, as though they were only the remnant of a much more extensive gravelly plain. Their preservation may be partly due to the greater thickness of deposit at that point, but are more probably due to the fact that they lie on the summit of the watershed between White River and Waterholes Creek. Their hills are capped with a deposit of western gravel 5 to 10 feet in thickness, resting on a drab-colored loam. Upon these hills were found a few bowlders, one a dark hornblendic gneiss 3 feet in diameter, another of gray granite, smaller. Upon the crest of the watershed southeast of these hills several other bowlders were found, but none to the south

or southeast, except two on the summit of a similar butte 3 or 4 miles southeast of the last-mentioned hills, which rise to the same level. Upon this were found a large bowlder of white limestone, about 5 feet long, and a smaller one of gray granite. Similar buttes farther south, rising from the valley of the Waterholes, showed abundant blocks of Tertiary quartzite, but few pebbles, and no traces of northern drift.

Excepting the cases already mentioned, no northern bowlders were found over the region south of White River. Immediately east of these hills is the wild gorge of Waterholes, and west the shallower valley of a tributary of White River. If traces of drift were formerly more abundant, as is possible, the great erosion connected with these valleys has removed them. The deposit along American Crow Creek is mostly on the south side, 24 miles from the Missouri. It closely resembles the extensive gravelly plain south of the White River, before described. It lies at an altitude of about 350 feet above the Missouri. It is about a mile in width and dips slightly to the north and east. The region between the lower portion of Medicine Creek and the Missouri has not been closely examined, but from its general appearance from the top of Medicine Butte, and its elevation, it is unhesitatingly put down as belonging to the scattered bowlder region. In the valley of Medicine Creek, west of Medicine Butte, no trace of drift was found, but on the summit of the watershed, about 2 miles south of the peak, drift was noticed. A ride of a dozen miles to the southeast disclosed none except in the close vicinity of American Crow Creek. The general level of the gently undulating plain occupying the whole region is from 450 to 500 feet above the Missouri.

ANCIENT CHANNELS.

As before stated, the region is traversed by broad valleys. These are found for the most part to coincide with present streams. Their elevation above the Missouri is from 200 to 300 feet. One valley extends from American Creek at Pukwana southwestward past Red Lake in a direct line to the Missouri River. This channel is from 1½ to 2 miles wide, and is occupied in its deepest portion by Red Lake, a shallow body of water 4 miles long and 2 miles wide. It is named from the abundance of reddish weeds which appear along its shores and cover considerable of its surface in the latter part of summer. Just east of Pukwana, and extending for 5 or 6 miles up American Creek, is an ancient lake, which has been filled. The level surface, the eroded spurs, and the sand and gravel struck within a few feet of the surface leave no doubt concerning the fact.

The heads of these various valleys connect in several cases with gaps in the moraine. Crow Creek, 5 or 6 miles southwest of Waterbury, crosses the moraine, which is there attenuated and broken. The northern and larger branch of Smith Creek in a similar way crosses, just northwest of Crow Lake, the faintly developed loop of the moraine, which

hed south down the west side of Turtle Ridge. The east branch cts with the internal drainage system of Turtle Ridge and the ɔefore described southeast of Crow Lake. Two of its southern ;aries rise near the moraine, one at the gap near White Lake and ;her at a gap 5 miles northeast of Kimball. American Creek heads ə moraine near Kimball, and receives tributaries from the outer of the moraine farther west. Snake Creek heads near a gap or uated portion of the moraine south of the Bijou Hills. Another course from the same stream extends north through Bijou Gap d the lower part of the moraine, north of the East Bijou.

BOWLDER RIDGES.

emarkable feature of these valleys in their upper course is the nce of numerous sharp bowldery ridges extending parallel with course. These resemble those already described in connection the gap near Crow Lake, and probably are of the same origin. are from 5 to 15 or 20 feet in height, and frequently show a clus- arrangement. One system was noticed extending along the south ɔf the valley of Smith Creek near Lyonville. Another along the ;ary valley from the vicinity of Kimball. Another, less conspicu- ras noticed along the American Creek Valley. In this case a tend- to a transverse arrangement was noticed. It is not unlikely these formed in a different way.

OLD WATER LINE.

other and still more remarkable feature, already alluded to, is a of water lines. This was first noticed in the vicinity of the West Hill. As one ascends its northern side the bowlders suddenly dis- ır at an apparently horizontal line. None are found upon the sum- ıor anywhere upon the southern slope above that level. The drift ɜs on that side lie as low foothills between the higher spurs extend- ɔm the hill. Erosion has frequently made the line between the two distinct. Upon the northern slope a line of more prominent foot- or an eroded terrace, corresponding to this line, is quite distinctly n. Around a high conical hill about 3 miles northwest of the gap rift is found to disappear at about the same level. The border of riftless region south of Crow Creek has not been examined with ɜnce to this point. West of the Missouri the bowldery ridge, dy mentioned as lying south of White River, is presumably near ame level; the distance between the two localities renders an determination with the barometer impossible. Other features ə upland of this region are provisionally referred to the action of nts of water. In the channel passing through Bijou Gap, a little ı of the gap, is a marsh covering several acres. Southeast of the eparating the West Bijou from the Brick Kiln Buttes are three or slight basins trending southeast. Trailing southeast from each

of the Brick Kiln Buttes, though now detached from them by circu denudation, is a long southeast ridge. One of these, where studie showed itself to be capped with loess-like silt, although its core largely Cretaceous clay. Southeast of Medicine Butte is a shallo marshy basin covering perhaps 2 square miles. Its longer axis poin toward a sag in the low swell running east from the butte. South this lake 3 or 4 miles are two much smaller marshy basins in a bro sag running southeast to the valley of American Crow Creek.

ELEVATIONS.

The elevation of the prominent points of the region, as given in tl subjoined table, will furnish a more accurate idea of its topography:

Elevations in the Red Lake region.

[All are barometric except those marked r, which are derived from railroad levels.]

Locality.	Above the Missouri.	Above the sea.
	Feet.	*Feet.*
Missouri, foot of Great Bend	.....	1,334
Summit of drift terrace in the Bend	235	1,590
Bluffs east of river	340	1,695
Summit between Missouri and Boxelder, 10 miles east	425	1,780
Boxelder Creek east-northeast	255	1,610
Gravelly terrace just west	372	1,725
Summit of moraine northeast	435	1,790
Missouri at Fort Thompson	.....	1,341
Drift terrace east	320	1,660
Summits 11 and 16 miles east	420	1,760
Valley of Elm Creek between	285	1,625
Boxelder Creek	210	1,550
Terrace just east	335	1,676
Moraine 4 miles east of Boxelder	425	1,765
Medicine Butte	875	2,100
Lake southeast	400	1,725
Plain east, average level	430	1,750
Bluffs west of Chamberlain	325	1,645
River at Chamberlain	.....	r1,321
Bluffs east of Chamberlain	325	1,645
Summit 5 or 6 miles northeast of Chamberlain	460	1,780
Gravelly terrace between Smith and Crow creeks	230	1,550
Summit 5 miles northeast of Pukwana	380	1,700
Pukwana	216	1,537
Ancient lake northeast	210	1,530

Elevations in the Red Lake region—Continued.

Locality.	Above the Missouri.	Above the sea.
	Feet.	*Feet.*
Red Lake	204	r 1,525
Kimball	458	r 1,779
Moraine near Kimball	500	1,820
Moraine southeast of Red Lake	325	1,645
Gravel-topped buttes 5 or 6 miles southwest of mouth of White River	570	1,880
Bowldery ridge northeast of last	510	1,800
Gravelly plain south of old valley of White River	360	1,665
Terrace of White River 6 or 8 miles above its mouth, capped with drift and loess	225	1,545–1,500
Missouri at mouth of White River		1,308
Terrace north of mouth of White River	300	1,610
High hill south of the junction of Red Lake Outlet with the Missouri	460	1,765
Conical hill northwest of Bijou Gap	620	1,930
Moraine north of East Bijou	470	1,775
The driftless region 4 miles west of river	500	1,790
Bluffs near Rosebud Landing	450	1,740
River at the Bijous		1,290
Larger Brick Kiln Butte	710	2,000
Summit of ridge trending southeast	600	1,890
Summit of West Bijou	690	1,980
Bijou Gap	460	1,749
Upper limit of drift around western Bijous	590	1,880
Summit of East Bijou	710	2,000

NOTES FROM WELLS AND OTHER EXPOSURES IN THE RED LAKE REGION.

Natural exposures displaying the drift are almost entirely wanting. Burrows of badgers and pouched-rats not infrequently display the subsoil, but no more. Wells, the only artificial excavations available, rarely pierce through the drift, and are generally so curbed as to afford no opportunity for direct examination. The statements of well-diggers and other reliable persons who were present when the well was dug, with illustrative material around the mouth of the well, have been necessarily the main reliance in most of the cases tabulated below. Red Lake is given as a base of reference. Steep banks, mostly grassed over, have supplied a little information, which is in general valuable, but not exact.

Data from wells and other exposures in the Red Lake region.

[These data were collected before 1888. There has been no opportunity to tabulate later data.]

Locality.	Elevation above Red Lake.	Description.
	Feet.	
Bottom of ravine, 4 miles west of Pukwana.	45	20 feet deep; 6 feet in "soapstone."
Three miles west of Pukwana.	105	75 feet yellow till above, the rest blue pebbly clay; 1 foot water.
A few rods southwest of last, in a basin.	100	17 feet; plenty of water.
Pukwana, on terrace of an old lake.	10	12 feet yellow till above, 3 feet water; abundant water.
Three miles northwest of Red Lake, edge of basin.	75	3 feet black soil, 8 feet yellow till, limestone and other pebbles, blue till in the bottom.
Three miles west of Red Lake.	85	60 feet through yellow till and gravel, "no blue clay;" good water.
One mile south of south end of Red Lake.	40	16 feet soil, yellow till and sand, 24 feet blue till; no water.
Another near by.....	40	16 feet yellow till and sand, 20 feet blue till; no water,
A little west of last...	40	14 feet soil, yellow till and sand, blue till touched; plenty of water.
On flat southeast of Red Lake.	15	3 to 4 feet soil, 25 feet yellowish and reddish pebble clay, and sand below.
Five miles south-southwest of Red Lake.	160	A few feet yellow loamy till; pebbles not very numerous.
One-half mile east of last, in a basin.	160	Large pile of reddish-gray pebbly clay thrown out.
Five miles north of West Bijou.	215	5 to 6 feet "old soil," 6 to 7 feet yellowish silt with calcareous concretions.
Eighty rods north of West Bijou, on knoll.	270	6 feet yellow till, little soil (a cellar).
A mile west of southwest angle of East Bijou, on a ridge.	235	40 feet soil, then yellow pebble clay, then sand, then bluish dirt which grew harder, 52 feet soapstone.
At foot of southwest angle of East Bijou.	210	40 feet loose clay.

Data from wells and other exposures in the Red Lake region—Continued.

Locality.	Elevation above Red Lake.	Description.
	Feet.	
Two and one-half miles southwest of southwest angle of East Bijou.	180	Struck blue clay (Cretaceous) at 28 feet.
Sec. 28, 4 miles south of East Bijou, southwest slope of high hill.	280	All bluish clay.
Sec. 28, west center ...	245	30 feet yellow till, 25 feet soapstone; little water.
Sec. 28, southeast corner, in a ravine.	230	16 feet yellow clay, a little water, 15 feet blue pebble clay, 4 feet "black soil," "soapstone."
South of west end of West Bijou.	225	38 feet yellow pebble clay above, "black clay" below, then 2 feet of "soapstone."
Bluff 1 mile northeast of Chamberlain.	85	60 feet drift.
Bluffs east of Chamberlain.	115	5 to 10 feet loess, 70 to 75 feet drift, a reddish checky clay 50 feet below top.
Bluffs 2 miles south of Chamberlain.	145	5 feet soil and loess, 1½ feet yellow and drab dirty sand, 40 feet pebbly clay, quite gravelly, above drab clay.
Bluffs south of Red Lake Outlet.	240	20 feet drift above, yellow, loamy, bowldery clay below, a gravel bed, bowlderets, 50 per cent Bijou quartzite, 25 per cent white limestone, some bowlders 2½ feet thick.

EXPLANATORY HYPOTHESES.

Such are the general facts derived from a study of the region, and we naturally look for some hypothesis by which they may be explained. There are but two which present themselves. One is that this region—at least so much of it as is now covered with till—at some time previous to the formation of the moraine was covered by the ice sheet, which was either too thin or occupied the region too short a time to obliterate the pre-Glacial topography. The other hypothesis is that the dispersion of drift was accomplished by floating ice in an expansion of the Missouri, covering the region contemporaneously with the occupation of the moraine.

In favor of the first theory it may be urged that till is believed by many to be an ancient ground moraine; also that the occurrence of basins and bowldery ridges resembling those of glaciated areas can not be otherwise explained. Furthermore, topographical conditions seem somewhat favorable for the extension of a lobe westward between White Lake and the Bijou Hills, and such corresponds well with the observed distribution of till.

Against this hypothesis the following considerations may be urged:

First. If we make the extension of the ice correspond to the present distribution of till we must suppose such an extension both north and south of the Bijou Hills by an ice sheet, which, at least around the West Bijou, could not have been more than 100 feet in thickness, and extending on that level at least 3 miles around the East Bijou, while in less than 40 rods it must have risen from 100 feet to considerably over 300 feet in thickness. Or, if we postulate first a thin ice sheet of greater extent, and later a much thicker one of less extent, we find no adequate room for the drainage during the occupancy by the second ice sheet.

Second. Such an extension must have passed more than 15 miles beyond the moraine about Red Lake, while in the northern portion of the region it extended in some places less than 2 miles. Such difference in fluctuation at nearly or quite equal altitudes is incomprehensible.

Third. This hypothesis fails to offer a rational explanation for the scattered bowlders which cover by far the greater portion of the region under consideration.

Accepting therefore provisionally the other hypothesis, we may explain the facts discovered as follows: During the first advance of the ice sheet streams to the north and west of this region, finding their courses checked to the east, may have escaped around the edge of the ice; at first around north of the Wessington Hills; later down east of the Ree Hills southeast to White Lake; still later from the Great Bend to the White River and north of the Bijou Hills. Or, if we assume that the Missouri in this region dates back to pre-Glacial times, we may forego these suppositions. But finally the ice reached the Bijou Hills and soon after its greatest extent to the mouth of Pratt Creek. At this stage the water over the Red Lake region rose to its highest level, deposited the scattered blocks everywhere, and began the accumulation of till along the southeast side of the basin. The influx from the White River formed the highest gravel terrace, which was probably rendered the more easy by the derivation of material from the conglomerate strata of the buttes near by. The till filled to the water level in the vicinity of Bijou Hills. The accumulation of the till in this portion, rather than elsewhere, may be accounted for by the occurrence of gaps through the moraine—at that time, of course, larger than later—north of Kimball and north of the Bijous. The ice lobe of the Ree Valley may not have attained its maximum extension at this stage because of the greater elevation of its bed.

The outlet of this basin through the Bijous and around the ice at Pratt Creek probably soon cut down to the 350-foot level by the deepening of the channel west of the Bijous. The till continued to form in the southeast portion. The lower gravelly terrace south of White River was formed, as also the accumulation south of American Crow Creek. The Ree lobe with its branches had meanwhile reached its position, and the high bowldery terraces along the Missouri at the Great Bend and along Boxelder Creek were forming, and the upper portions of other important streams of the region were outlined. The formation of some of the osar-like ridges in these valleys are possibly to be referred to this stage.

During the thinning of the ice sheet these streams became unusually laden with silt, while ice blocks became rare, because of the stagnation of the ice, and a thin mantle of silt overspread the region below this level. As the melting of the ice sheet continued in its recession to the position of the second moraine, the channels were gradually deepened to about the 200-foot level. Most of the osar-like ridges were formed, and faint bowldery terraces of the Red Lake channel, which may be referred to a reassortment of local material rather than to that directly derived from the ice sheet.

More space has been given to this region because of its unusually clear bearing on the questions connected with glacial and glacio-natant action, which will be further considered in connection with the loess region, where the phenomena are more complicated.

PONCA REACH, OR REGION FROM MOUTH OF PRATT CREEK TO MOUTH OF NIOBRARA.

This region presents striking contrast with the last. It is narrow and straight. Its outer margin at no point is more than 3 or 4 miles from the river, nor more than 15 miles from the inside of the moraine. Its southwestern limit ends very abruptly along the edge of a high table-land corresponding geologically with the Bijou Hills, and rising abruptly 450 to 600 feet above the Missouri. The Missouri, from Pratt Creek to Fort Randall, lies in a narrow gorge, from 2 to 3 miles wide most of the way, with a high bowldery terrace along its left bank, at an elevation of 175 to 250 feet. Lower alluvial terraces are scantily developed. On the right bank the frowning edge of the table-land before mentioned rises abruptly from the river, except in the bend above the mouth of Whetstone Creek, where the bowldery terrace is finely developed, and at Fort Randall, where a high alluvial terrace is found.

Viewing the bluffs south of Pratt Creek Gap from about 12 or 15 miles north, they appear rising above the glaciated plain to about the same height as the Cedar Creek Hills to the left, which are, as before stated, a portion of the moraine; and they are at a lower altitude than the ancient water level in the vicinity of the Bijou Hills. From both

considerations it would seem impossible, under the lacustrine hypothesis, that they should not at some time have been more or less covered with drift; nevertheless, no drift is now found upon them, and not even in the valley of Whetstone Creek did a considerable search reveal any bowlders or northern gravel. This is the more remarkable because the surface of the country drains southward into Whetstone Creek from the crest of the bluffs overlooking the Missouri River on the north.

The southwest side of the river was examined again near Fort Randall, and nothing was found higher than about 425 feet above the river which could in any wise be considered of northern origin except a very few scattered pebbles. The examination was continued for 15 miles, to the summit of the divide between the Missouri River and Ponca Creek, 600 feet above the former. Much of the surface traversed was about 450 feet above the river, and was crossed with shallow valleys extending from the northwest to the southeast. The surface was a dark loam, but the subsoil everywhere showed either the clays of the Cretaceous or, upon the high hills, the sands, marls, and gravel of the Tertiary.

From the vicinity of Fort Randall to the mouth of Choteau Creek the moraine is more remote from the river. Its outer slope, which shows the usual billowy appearance of hills, is ravined by two or three considerable brooks, which rise near the crest of the moraine and run nearly directly south to the river. Their upper tributaries occupy a more or less defined valley just outside of the moraine and parallel with it. This slope extends down to the high terrace before mentioned, which is here from 1 to 4 miles wide. This terrace shows a very even surface, sloping from a height of 250 feet at its outer side to about 200 feet along its inner edge. An interesting feature appears about 5 miles northeast of Yankton Agency, where the northern edge of the terrace is marked by an abrupt bank, facing southwest and extending for a mile or two. It is over 75 feet in height. Where the terrace was observed in the vicinity of Greenwood, near a stream, it was 130 feet above the river. There it is capped with 10 to 15 feet of silt, below which it is very gravelly and contains bowlders for a dozen feet or so. Lower down it presents the usual features of till. About 4 miles west of Choteau Creek its edge is 200 feet above the river. Its surface is free from bowlders and pebbles, being generally covered with a deep layer of silt. Below this a layer of 30 to 40 feet of loose yellow and reddish till prevails. Farther east, where its surface is ravined and cut into knobs, a wonderful profusion of limestone bowlders is found.

Upon the south side of the river the table-land before mentioned retains its altitude and terminates on the northeast sharply with the top of the river bluffs. It continues with scarcely diminished height to the mouth of the Niobrara, where it terminates abruptly.

Along this portion of the river a very narrow terrace hanging to the abrupt south bank, as seen from a distance, was judged to correspond to that on the north side. From the mouth of Choteau Creek to the

mouth of the Niobrara the ice sheet seems *to have abutted closely* upon the river, much as at the mouth of Pratt Creek, but without pushing its moraine entirely into it, as it did a little farther east, in Emanuel Creek Gap.

Across the river is the eastern end of the southwestern table-land, rising abruptly from the junction of the Niobrara with the Missouri to the height of a little more than 300 feet. At this point it is a narrow, much-eroded ridge, but within 2 miles it attains an elevation of 400 feet and becomes a table-land more than 2 miles in breadth, which continues toward the west, both rising and broadening. Its slope is pronouncedly northward toward Ponca Creek. It is traversed by deep, narrow valleys running in that direction from the very edge of the bluffs overlooking the Niobrara. These bluffs are sometimes even lower at the head of the valleys, as though the escarpment on the south had moved northward since the valleys were formed. About 6 miles west of the mouth of the Niobrara heavy deposits of western gravel were found in knolls along the crest of the bluffs, about 425 feet above the level of the river at Niobrara. These are so left by erosion as to stand out conspicuously above the surrounding surface. A trip was taken along the line of the trail to a conical butte rising about 60 feet above the general slope around it and about 500 feet above the river. Upon it, and at several other points, numerous large blocks of Bijou quartzite are found, but not the first trace of either bowlders or pebbles of northern origin are seen upon the general level of the highland. Both, however, are found scattered in considerable numbers over the spur at the eastern end to the height of 350 feet. It is a noticeable fact that they occur at the higher levels only in the sags upon the crest, where erosion would be least likely to remove them. They are very rarely found on the slopes of the bluffs or upon the flat at their foot. The limit of the drift at this point is estimated to be not more than 4 miles from the inner border of the moraine where it is developed on the opposite side of the river. The ice sheet must have been much nearer at its maximum, and when we remember that all the drainage of the vast western edge of the ice sheet must have passed this point, we are forced to inquire why the stream did not erode its way farther south; why it did not rise in its flooded stage so as to carry the bowlders (for there must have been some river ice, bearing drift, in glacial ice blocks) to a much higher level, to at least 450 feet, the level of blocks less than 4 miles southeast. It is clear that either this table-land was above the level at that time, so that they could not be deposited, or, if deposited at a lower level, erosion has been sufficient to wholly remove them.

The before-mentioned gravel beds along the Niobrara evidently correspond in elevation to the extensive sheet of gravel south of the town of Niobrara. From a distant view it is judged that these beds were connected through gravelly (?) knolls in the sharp bend of the Niobrara a few miles above its mouth.

LOESS REGION.

BOUNDARIES AND SURFACE.

Although the word loess may suggest the whole area covered by that deposit, the boundaries of that region are so vague that we adhere to our original plan of limiting our description chiefly to the surface covered with drift. We therefore turn our attention first to the—

WESTERN BOUNDARY OF GLACIAL DRIFT.

This also has been less accurately determined in this region than in the preceding. The principal difficulties met in an attempt to determine it are as follows:

1. The deep and almost universal covering of loess, which extends much farther westward.

2. The gradual passage of the northern or glacial drift into a western or fluvial drift, which has been found to occur along the principal streams from the west. The distinctions which have been relied upon in the determination of the former have been the occurrence of erratics of red quartzite and white and yellow Silurian limestones; also the striation and abrasion of pebbles peculiar to glacial drift. On the other hand, the western drift presents lithological characters similar to those which have been previously recognized in the discussion of the Red Lake region, and the pebbles are only waterworn.

3. The covering of the northern drift by the western. This may lead to wrong conclusions where exposures are incomplete.

4. The erosion and removal of the drift itself underneath the loess. This renders the upper surface of the drift very uneven, and because no drift is found upon the surface of a hillside one may fancy that none is present, where an exposure may reveal it as not only present, but rising high in the center of the hill.

So far as yet determined the western limit may be stated as follows: From the junction of the Verdigris with the Niobrara southeast, passing a mile or so east of Creighton, 5 or 6 miles east of Plainview, and east of Pierce to the vicinity of Norfolk; thence south along the western line of Stanton County, swinging to the east in Colfax County to the vicinity of Richland; thence in the same direction, passing 3 or 4 miles east of David City, south along the east side of Plum Creek to the vicinity of Seward; thence south and southwest, passing west of Norval post-office to the vicinity of Friend; thence southwest indefinitely. That one may estimate as justly as possible the value of this determination the subjoined data are given.

1. Localities visited which are beyond the drift, with a few others reliably reported:

(*a*) No drift is found anywhere west of the Verdigris[1] nor between

[1] Later investigation has developed the occurrence of a few syenitic bowlders upon the high terrace near Verdigris Valley, 180 feet above the stream.

the Verdigris and Bazile south of Sparta post-office. The Tertiary and Cretaceous rocks appear in that region in several places below the loess without the drift intervening. (*b*) On the south side of the valley, at Plainview, a bed of western gravel several feet in thickness was observed, but not the slightest trace of northern erratics. None have been found after a persistent search upon uplands for several miles west and north of that town. (*c*) The Yellowbank, north of Battle Creek, exposes a straight section 120 feet high, in which 60 feet of fine sand rests on the horizontal surface of 60 feet of compact drab-colored clay; no fossils or pebbles in either. On a side hill, a little northeast, considerable western gravel was found, but no northern erratics. (*d*) From Norfolk to Columbus no drift was noticed in passing on the cars and none learned of by inquiry. (*e*) On a high steep hill facing Shell Creek, near Platte Center, numerous pebbles and a few bowlderets were found resting on Tertiary clays. None were of distinct northern origin; none were striated, and most have a decidedly western character. (*f*) In numerous deep cuts north of David City and in the south side of the Platte Valley no pebbles of any sort were found. (*g*) Four miles south of David City a recently bored 80-foot well showed only a few western waterworn pebbles in a yellow clay. (*h*) The unanimous testimony of well diggers is that west of Plum Creek, which runs south from near Brainard to Seward, no "hard heads" or pebbly clay are struck in wells, though they are uniformly much deeper than those east of that line. In both regions the deposits are similar down to what is commonly called the "old soil." Below that point those west of the line indicated show sand only, while those east exhibit bowldery clay. (*i*) Nothing but western gravel was found in the vicinity of York, and general testimony is to the effect that no "hard heads" or pebbly clay are found west of Seward.

2. On the other hand, in the following localities the glacial drift has been directly observed. A few others of which reliable information was obtained are added, but carefully distinguished.

An extensive sheet of gravel was observed south of Niobrara. A thin deposit begins a mile east of Creighton. There are numerous exposures of yellow till from Osmond east for 5 or 6 miles, and there is abundant pebbly clay with bowlders at the insane asylum 1½ miles northeast of Norfolk. "Hard heads" are reported as abundant 3 or 4 miles east of Pierce. Yellow and blue till with northern bowlders was found on Maple Creek in the northern part of Colfax County. Red quartzite pebbles were found in quantity 5 miles northwest of Schuyler. Northern bowlders and pebbles are abundant on the bluffs south of Linwood, and less prominent about the head of Bone Creek 5 miles east of David City, also south of Brainard in Butler County. Bowlders abound on hillsides and in ravines generally east of Plum Creek and of the Big Blue in Seward County. Drift is shown several feet in thickness in a high bank on the Big Blue 9 miles southwest of Milford. Red quartzite

bowlders and other traces of glacial drift were observed in abundance south of Pleasant Hill in Saline County, and are reported in the vicinity of Fairbury, Jefferson County.

EASTERN BOUNDARY OF GLACIAL DRIFT.

Theoretically the eastern boundary of this region should coincide with the extension in that direction of drift material which has been dispersed by ice of the Dakota lobe either as a glacier or as icebergs. On either supposition a mingling of material with that which was dispersed from the Iowa lobe would be unavoidable; consequently there would be more or less drift from the northeast in the area under consideration. So far as is known, no lithological distinction which would be decisive in this case can be drawn. Red quartzite and white limestone erratics are found inside both the Dakota and the Iowa loops of the moraine. The rock most likely to be of service in this respect is that from the Missouri Coteau, which resembles buhrstone,[1] but it occurs in such small fragments, and so rarely, that it must be of little service. The phenomena of most practical value which are likely to be found are striæ upon the underlying rocks, which show motion from a westerly direction. Topographical relations may also have some weight. So far as is known no such striæ are found in this region east of the immediate valley of the Missouri. Farther north, however, striæ are found in such relation to the Dakota loop of the moraine as will warrant us in placing the boundary which we seek far east of the Missouri. In Minnesota striæ from the northwest, or even from more nearly west, are found at Pipestone, also at a point 7 miles south of Pipestone, according to Mr. Warren Upham of the Minnesota survey. Numerous striæ have been observed also north of Valley Springs, South Dakota, from N. 62° W.

This gives us reason for locating, provisionally, the eastern boundary quite remote from the Missouri. It may nearly coincide with the eastern boundary of the loess deposit as given in a later section. A small bowlder resembling burhstone was found at Cherokee, on the Little Sioux, and another east of Shenandoah in Page County, Iowa, and it is not improbable that the eastern boundary should nowhere be nearer to the Missouri River than 30 miles.

As before stated, the southern boundary is arbitrarily set at about 100 miles from the moraine. The southern limit of the drift would lead us beyond the scope of this paper.

DESCRIPTION OF SURFACE.

Elevation.—The surface of this region is considerably higher than that within the moraine; south of Emanuel Creek Gap the difference is about 250 feet, and east of Big Sioux Gap 150 feet. Along its western

[1] This has been determined to be of Miocene age and formed apparently in marshes bordering the lakes of that epoch.

side the average altitude of the highest points is nearly 1,700 feet, while along the Missouri it is about 1,400 feet. The whole region slopes toward the south and east. This is shown by the following list of elevations. They are mostly barometric, but closely connected with points determined by railroad levels. Only such points are taken as lie in the general level of the country.

List of elevations in the loess region.

	Feet.
From north to south:	
Bluffs south of Herrick, Nebraska	1,750
Hills north of Plainview	1,825
Hills near Battle Creek	1,816
Plain south of Humphrey	1,690
Plain at Osceola	1,680
Plain at York	1,662
Plain at Fairmont	1,656
Bluffs at St. Helena, over	1,400
Summit of the divide southwest of Hartington	1,710
Hilltops southwest of Coleridge	1,840
Summit southwest of Northside	1,830
Summit 8 miles south of Stanton	1,800
Bluffs 5 miles northwest of Schuyler	1,610
Plain at David City	1,619
Higher knolls	1,650
Plain at Germantown	1,584
Plain at Dorchester	1,501
Hills west of Ponca	1,375
Hills west of Emerson	1,630
Hills east of West Point	1,526
South of North Bend	1,450
Hilltops near Wahoo, over	1,300
Plain at Cheney	1,435
Knolls at Cheney	1,460
Southeast of Valley Springs	1,510
Plain at Warren, Iowa	1,465
Hill east of Akron	1,415
Hilltops south of Blair, Nebraska	1,350
South of Louisville	1,225
Near Turlington	1,195
From east to west:	
Bluffs near Platte Center	1,645
Bluffs near Schuyler	1,610
Summit near Mapleville	1,432
Summit west of Kennard	1,285
Hills west of Calhoun	1,250
Guthrie, Iowa	1,290
Plain at Friend, Nebraska	1,575
Knolls at Friend, Nebraska	1,600
Plain at Dorchester	1,500
Hilltops northeast of Crete	1,450
Cheney, general level	1,435
Cheney knolls	1,460

It may be conceived that at least the western portion of the region was at one time a nearly level plain, out of which the valleys of the present streams have been excavated. The original surface of the plain has been quite perfectly preserved away from the larger streams. Between the Platte and the Elkhorn this is true as far east as the headwaters of Maple Creek. South of the Platte the plain extends as far east as David City and the Big Blue. Traces of the plain, in the form of high flat-topped hills, are found as far east as the Missouri and beyond; but the whole region was probably never filled to a level plain. Several things seem to indicate that when the region was first vacated by the depositing waters it was not a completely filled basin. We would not assume to decide between a lacustrine or fluvial deposition; probably both played a part. We proceed to give some of these because they also illustrate the peculiarities of the present surface.

Basins and knolls.—Even when the surface is most nearly a perfect plain, as in the region west of the Big Blue, there are shallow basins with clayey bottoms and corresponding swells. Along south of the Platte about Osceola the same is true, and farther eastward about David City both features are upon a grander scale. Some of the basins are more than a mile in breadth and the knolls and ridges from 25 to 40 feet. The aspect suggests the former extension of a shallow lake in which there were low islands or bars. Farther north, about the headwaters of Logan Creek, similar features, though much modified by erosion, are noticed in the topography, but erosion has cut down the basins, leaving the hills much more elevated, though still showing the same isolated and irregular arrangement. Doubtless winds have had a mild dune effect upon the loess.

Elevated ridges.—In the northern part of the region under consideration a conspicuous feature of the topography are the high, somewhat discontinuous northwest-southeast ridges. One extends from near the mouth of the Verdigris to the vicinity of Bazile Mills. Another begins east of Santee Agency with a lofty spur running out several miles from the northern edge of the table-land north. It extends down into the southeast corner of Knox County. Another begins southeast of Yankton and extends southeastward to the West Bow. Another begins near St. James and extends southeast into Dixon County, and possibly into the Winnebago Reservaton.

These ridges are more narrow and conspicuous toward the north, and may possibly be looked upon as the high watershed separating the intervening streams. Their surface features are doubtless due to erosion, but the prevalence of this direction remains unexplained. We must look for it in some peculiarity in the original surface where the courses of the present streams were begun.

In the list of elevations given, the summits of these ridges were taken rather than of lower surfaces between.

Ancient channels.—This directs our attention to another problematic

feature. This embraces certain channel-like valleys which are found in northern Nebraska crossing the divide between the tributaries of the Missouri which run in a northerly direction and those which have a southerly direction. Their characteristics are best preserved upon the watersheds, because there they are least modified by erosion. The one passing near Coleridge, Nebraska, may be taken as a type of the whole. It connects Bow Creek with the upper waters of Middle Creek, a branch of the Logan. It is a valley from 3 to 4 miles in width, showing two or three subordinate channels or intervales running approximately parallel with one another and depressed from 30 to 50 feet below the broad, flat ridges between them, which at one time may have been bars or islands in the ancient stream. These terrace-like ridges are covered with a thin layer of loess, under which is found gravelly clay 20 or 30 feet higher than the channels. In the bottom of the channels, after penetrating the soil, which is deep and rich, sand of indefinite depth is struck. Coleridge, which occupies the summit of this channel upon the divide, has an altitude, according to railroad levels, of 1,672 feet. The altitude of a high loess ridge southwest of Coleridge is 1,800 feet, and a similar ridge 5 miles east of Coleridge is about 1,825 feet high. Northwestward from Hartington the general surface is much eroded and distinct traces of the channel are not found. However, there is nothing to forbid the opinion that the channel formerly extended in that direction.[1]

A similar channel passes from the Verdigris to the Bazile at Creighton, thence southeast up the latter stream to Plainview, where it is 1½ miles in width, and does not present the complex appearance which was noticed at Coleridge. From this point it continues in a direct southeasterly direction to the north branch of the Elkhorn at Pierce.

A smaller valley, which passes from the east branch of the Bazile at Kemma southeast to the north branch of the Elkhorn, presents similar characters. These channels in Nebraska are all much eroded toward the northern end by existing streams.

Areas sloping away from principal streams.—Another character of the topography, which is unlike that usually found in the chance arrangement of streams upon an even plain surface, is the frequent occurrence of drainage from the immediate vicinity of the principal streams to some subordinate stream. This is remarkably true along the southern side of the Platte Valley. For nearly 100 miles the waters falling immediately south of the edge of the bluffs, instead of making their way into the Platte, are carried away southward into the tributaries of the Big Blue. Even where small streams turn northward, as Bone Creek and Skull Creek, the bluffs rise precipitously next to the Platte Valley, and the waters, which eventually flow northward, are first turned south-

[1]Since the above was written, facts and considerations presented by Gilbert, Bain, Udden, and others have led the writer to give greater prominence to wind action in explaining the irregularities of surface mentioned.

ward through the narrow valleys of these creeks. So with the Elkhorn on its southern side from the vicinity of Wisner to Scribner, the land slopes from the very top of the bluffs southward and southwestward. Along the northern side the same feature prevails. Such subordinate streams as Plum Creek, Cuming Creek east of West Point, Bell Creek, and the west branch of the Papillion, draw from the very summit of the bluffs along the Elkhorn. The same feature may be occasionally found along the present valley of the Missouri, but its greater depression and the probably less original elevation of its bluffs render it less prevalent and less evident. On a grander scale the whole of the northeastern corner of Nebraska may be instanced as an example of this feature, sloping, as it does, away from the eastward-flowing portion of the Missouri. Along the east branch of the Big Sioux, from the northern line of Iowa southward, a similar relation carries the waters from its near vicinity into Rock River.

All of these features, when traced back to their beginning, point toward inequalities in their original surface of greater or less magnitude. Further reasons for believing that this original surface was uneven will be found in the section treating of the relations of the loess to the drift.

Principal streams.—The central stream is the Missouri. Its valley north of Yankton resembles in every respect that in the regions already described, but east of Yankton it puts on quite a different appearance. While its bluffs are still high along the south side, they show no older formation except near their bases. The valley suddenly widens to a breadth of from 8 to 10 miles. This breadth it retains to the mouth of the Big Sioux, where it is somewhat increased. South of Sioux City it attains a breadth in places of more than 15 miles. At Blair the valley begins to narrow, and near Rockport, southeast of Calhoun, it is about 3 miles wide. It is a significant fact that at this point the Carboniferous limestone begins to appear near the water level. Farther south the valley is very rarely more than 5 miles wide, and while the slope of the stream from Sioux City to this point has been about 6 inches per mile it now increases to 1 foot per mile, which it continues to the southern line of Iowa. The valley of the Missouri is bounded everywhere in the loess region with steep bluffs of that material, rising 250 to 400 feet above the low, flat, bottom lands between. Where they have been longest subject to erosion the loess, which usually constitutes from one-half to three-fourths of the height, stands at an angle of from 40° to 60°, while drift makes a much smaller angle with the horizon, and the older rocks stand out as a shelf or shoulder.

Three important streams enter this region from the west—the Niobrara, the Elkhorn, and the Platte. The first, which barely enters, flows in a narrow valley 300 to 400 feet deep. The other two have very wide valleys, especially in their middle course, and are depressed from 250 to 300 feet below the general level. Their slopes nearly coincide with the slope of the region.

Tributary streams and creeks are numerous throughout the whole region. They are fed by perennial springs, and usually run in narrow ravines from 5 to 20 feet deep.

Terraces.—Although the subject of terraces will be treated more fully in another place, a few words seem called for in this connection. Along the principal streams the present flood plain is at an elevation of from 5 to 20 feet. The bottoms of their valleys are principally occupied by land upon this level. Traces of other benches from 15 to 30 feet are not infrequently of considerable extent. Besides these more recent terraces there are conspicuous traces on most streams of a terrace at from 60 to 100 feet above the present stream. Traces of this high terrace are found along the Missouri from Herman to De Soto, in Washington County, Nebraska; also in the vicinity of Fort Calhoun it is finely exhibited for several miles. At North Omaha and at Bellevue it has considerable extent and an altitude of about 50 feet.

Along the Platte we find a high terrace on the north side of the present valley extending from Hall County, where it is low and much obscured by sand hills, to the vicinity of Fremont, where it has an altitude of about 80 feet. Its northern edge is marked by the lower course of the Loup River, Shell Creek, and Maple Creek. There are ancient channels connecting these streams with one another at their nearest points. Its width is from 3 to 4 miles. From the vicinity of North Bend an old channel, 8 miles in width and on the same level with the terrace to the north, extends southeast along the east side of Sand and Wahoo creeks to the vicinity of Ashland.

Along the Elkhorn the terrace before mentioned, north of Fremont, extends northward on the west side of the Elkhorn to Scribner. Little trace of this terrace has been found above that point, partly because it is obscured by sand hills, partly because the region has not been fully examined upon that point.

Traces of this high terrace are found along Bazile, Beaver, Bow, and Logan creeks in Nebraska. In Iowa traces of it are found along the Big Sioux near Beloit and Fairview, and along several of the streams on the east side of the Missouri, which have not, however, been examined sufficiently to warrant a more complete description.

Elsewhere, and in general, the topography of the loess region finely illustrates the principles of erosion when applied to a homogeneous deposit. Remote from streams the hills have a gently rounded form, extending to the edge of the deep ravines which furrow the bottom of the valleys. These ravines increase in depth toward their head, where they terminate abruptly with perpendicular or even overhanging banks. Toward the principal streams the slopes of the hills gradually become steeper. Where undermined by eroding streams they frequently present bare perpendicular faces 20 to 50 or even 100 feet in height. In general the topography is of the erosive type prevalent in massive sandstone regions, for the loess resembles sandstone in its resistance to the various

weathering agencies. From its tendency to stand in steep slopes along the streams Professor Swallow, of Missouri, early named it the Bluff deposit.

Sand hills.—Beneath the drift over much of this region is a deep deposit of fine sand presumably belonging to the Pliocene epoch. In the northern portion of Cedar and Knox counties the lower valleys are much widened by the unusual recession of their sides, which may be ascribed to their undermining because of the presence of this deposit. The sand is considerably mingled with the soil and gives a pleasing smoothness to the landscape.

This sand deposit comes to the surface and occupies much of the country west of the Verdigris and the ancient channel before mentioned, which runs southeast from Creighton. The western boundary of the loess is there, and as far south as the Platte, obscured by the advance of the sand eastward. Sand hills and "clay hills" are indescribably mingled. The "clay" closely resembles, if it is not identical with, the loess. It probably is a deposit of the Loup River epoch. The ancient channel between Creighton and Pierce, more especially south of its summit, shows an interesting series of transverse ridges of sand, vast ripples, as it were, rising from 25 to 60 feet above the intervening clayey meadows. They are at quite regular intervals of 1½ miles. Traces of sand are found in the wash of the hillsides as far east as Cedar County. At several other localities also there occur sand hills which, though formed by the wind, have had their material brought into the region by the instrumentality of streams. The Elkhorn and the Platte, flowing through sandy regions, accumulate large quantities of sand in their bars and bottom lands. When this sand is driest and most widely exposed the whole region is subject to prevalent winds from the northwest; the result is that, wherever these streams run toward the southeast for some distance, large quantities of sand are blown from the valleys out upon the upland. In this way one may take a map and with considerable confidence tell where such sand hills will be found. They have been observed occupying several square miles south of Stanton. They are prominently developed, and are more conspicuous because of their elevation east and southeast of West Point. They are frequently interspersed with small ponds. South of the Platte they have been observed near the mouth of Bone Creek northeast of David City, and in a very extensive area south of Kearney. They also occur in corresponding positions along the branches of the Loup River. Much of the broad valley north of the Platte is occupied by sand hills.

DRIFT DEPOSITS OF THE LOESS REGION.

The drift of this region may become the subject of much controversy as concerns its origin. We therefore propose to present, as completely as our space will allow, the data which have been gathered.

TILL.

The lowest and most important formation is here, as elsewhere, the till. It presents the usual appearance of a homogeneous matrix of clay containing pebbles and bowlders scattered through it, with rarely any trace of stratification or segregation of any sort. It also contains irregular masses or pockets filled with stratified gravel, sand, or silt.

Color.—The prevalent color, when unaffected by weathering or leaching, is a bright lead blue. Sometimes, however, it is a dull grayish brown. It abounds, especially in its lower portions, in white pebbles of limestone and quartz, which in a fresh surface present a striking appearance upon the blue background. The upper portions of the till, where it has been long subject to weathering, or where the frequency of porous layers or seams has carried the surface waters into the clay, are of a yellowish appearance, which below sometimes shades into a reddish color and above into a dull buff.

Joints.—The clay always presents a jointed appearance, these joints running in all directions, dividing a deposit into polygonal masses. These masses are continually subdivided as the process of weathering goes on. In the freshly exposed blue till these masses may be 3 or 4 feet across, and the seams are correspondingly prominent. They appear in some cases, which we may consider an earlier stage, as mere cracks cutting the mass irregularly. They more frequently show traces of accumulation in the form of thin calcareous or selenite plates. Seams have been found where the selenite plates were from one-eighth to one-half inch in thickness. In some cases the selenite shows a coating of flour-like gypsum, and in some cases, toward the surface of the deposit, where it is more changed, the whole seam is filled with such material. The color of the blue clay adjoining these seams gradually changes through different stages to a dull yellow. As the selenite plates increase in thickness these weathered portions as a rule also increase in thickness. Some of the measurements of observed cases are as follows: Measuring from the center of the seam either way, one-eighth inch flour-like gypsum, one-eighth inch drab clay, three-fourths inch bluish, then the surrounding blue clay; another, one-half inch cream-colored core, 3 inches yellow clay, 2½ inches whitish yellow, then the blue clay. More convincing evidence in favor of the conclusion that the yellow till is merely the weathered portion of the blue could scarcely be imagined. This change of color in this case corresponds with what is uniformly observed of the drab-colored layers of the chalkstone, of the similarly colored beds of the Benton and the Pierre clays, and also of the blue limestone of the Carboniferous and Paleozoic rocks generally.

Local indications of subaqueous origin.—There are several features of the till in this region which favor the conclusion that it is of subaqueous origin. While the previous description may be taken without qualification as to general structure, there are exceptions found, as

deposit of volcanic ashes more than 3 feet in thickness, which, though very friable, shows no disturbance. About a mile east of Osmond it was found resting on a gray pebbleless clay, and conformably. In Mills

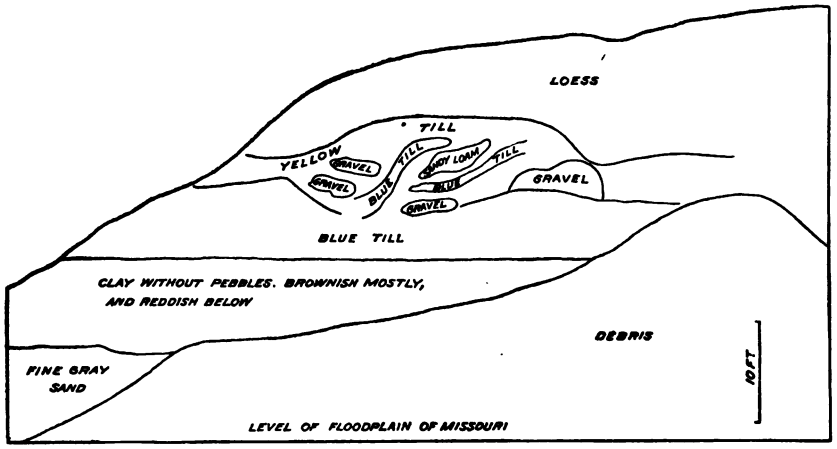


FIG. 14.—Exposure showing base of the till north of Pacific Junction, Iowa.

County, Iowa, typical blue till was found resting upon a grayish-brown clay from 5 to 10 feet in thickness containing no pebbles, and this in turn upon sand (fig. 14). Neither showed signs of disturbance. Near Ben-

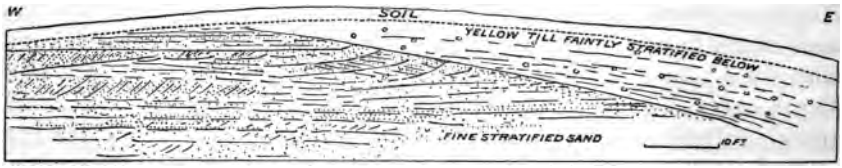


FIG. 15.—Exposure showing base of the till near Berks, Nebraska.

nett and Roca, Nebraska, drift was found resting upon Carboniferous clays without apparent disturbance. Near Berks, Nebraska, it was found resting upon an inclined surface of stratified sand with no traces of disturbance in either (fig. 15).

STRIATION OF UNDERLYING ROCKS.

While what has been given seems to indicate the general gentle deposition of the drift, at least in deeper or more protected localities of the old surface, there are a number of cases where great force has been exerted in a horizontal direction. Striæ have been observed in the following localities: About Sioux Falls the surface of the quartzite is planed and striated generally toward a direction varying from S. 8° E. to S. 43° E., but some were from the west. Southeast of Sioux Falls, about the northwest corner of Iowa, the surface of the quartzite is smooth and striated in a similar manner, in direction from S. 8° E. to S. 53° E., the majority of cases corresponding with the course of the Big Sioux.

A few miles north of Valley Springs striæ varying from *S. 8° E. to* S. 63° E. were abundant on the polished red quartzite. So far as is known, no distinct striæ have been observed on any other formation except the Carboniferous limestones south of the Platte in Nebraska and adjacent portions of Iowa. Very faint indications of motion from the north-northwest of superincumbent blocks of bowldery clay were noticed south of Roca, Nebraska. At Bennett, about 9 miles east, the surface of the limestone was found planed and covered with striæ indicating a movement S. 41° to 43° W. This was on the northeast side of a hill looking toward a valley opening in that direction. A rod or two west of that point a few striæ toward S. 17° W. were found, and still farther west at one point striæ were found toward S. 61° W. and S. 9° E. It is a notable fact that this latter locality was simply a few square feet of surface on the same level surface with many square rods of limestone which, though covered with till, showed no signs of smoothing or striation. On the north side of the valley a mile away another slight trace of striæ was found, indicating motion toward S. 88° W. South of Plattsmouth a considerable surface of the limestone, about 40 feet above the river, is planed with striæ from east of north.

Upon the limestone ledges 3 or 4 miles south of Pacific Junction, Iowa, striæ are found at localities differing about 50 feet in elevation. They are mainly of two sets, S. 9° E. and S. 40° E. Meek, in Hayden's Final Report on Nebraska (p. 92), records near the mouth of the Platte S. 10° W. [mag.]. Dr. White in his Iowa report, Vol. I, p. 94, mentions a locality opposite Council Bluffs, now obliterated, 6 to 8 feet above high water, where the direction was S. 41° W. Prof. S. Aughey, former State geologist of Nebraska, reported striæ near Beatrice, Roca, and Syracuse, also along the Platte at several points, which have an average direction of S. 19° E. In a quarry south of Unadilla, Nebraska, though no striæ were found, the different blocks in the upper layer were tipped down toward the north without being apparently moved from their position. Two miles northeast of Tabor, Iowa, planation was widely shown, but the stone is now removed and the direction has not been ascertained.

DISTRIBUTION OF THE DRIFT.

For convenience under this topic, we will divide the drift into Nebraska, Dakota, and Iowa divisions.

THE DRIFT IN NEBRASKA.

South of Niobrara, Nebraska, at an elevation of over 400 feet above the Missouri, is an extensive exposure of clayey gravel capping the hills. This seems to be from 15 to 25 feet in thickness and to rest upon light-colored clay. Farther south the loess appears above it, and bowlders abound in it, especially in its upper portion. East of the Bazile there is the same general appearance, but below fine sand begins to show itself in the sides of the bluffs.

Volcanic ash stratum.—Underneath the drift a layer of grayish-white volcanic ashes begins to show itself 5 or 6 miles southwest of Santee Agency and is exposed here and there for at least 6 miles eastward. The localities noted are SW. ¼ secs. 27 and 35, T. 33 N., R. 4 W. At the former place it is underlain by a stratum of laminated clay crowded with fresh-water shells. Prof. R. E. Call has determined them to be mostly *Limnophysa decidiosa*. This stratum has been observed to be more than 3 feet thick. The ash seems to pass both laterally and above into a whitish marl. Both are 450 to 475 feet above the Missouri River.

Mr. Andreas Lundteigen, chemist for the Yankton Cement Works, who was interested in the deposit from a business standpoint, has kindly given me the following analysis of a sample taken from the top of the former bed on Mr. Wakana's land: Silica, 72.44 per cent; lime, 0.55 per cent; alumina and oxide of iron, 14.78 per cent; loss by ignition, 4.28 per cent; total, 92.05 per cent. A sample from the bottom did not differ materially.

A stratum exactly similar in composition has been found near West Point (Pl. XI), on the West Blue southwest of Milford, and also along the Missouri about 7 miles north of Omaha, Nebraska (Pl. XII). At all points it occurs in the drift, not below it. At West Point it is found from 4 to 6 feet thick, at the second point 1 to 5 feet, and near Omaha 18 inches. Specimens were submitted to Mr. J. S. Diller, of the Geological Survey, who has pronounced them volcanic dust, composed chiefly (90 per cent) of minute angular fragments of pumiceous glass. Besides these are numerous (10 per cent) grains of quartz sand, well rounded, indicating that the ashes fell into quite water.

If, as seems not improbable, these different beds were deposited simultaneously, how may we account for their being below the drift in Knox County and in the drift in Cuming and Seward counties? By reference to a list of elevations further on we find the altitude to be now in the first case over 1,600 feet, and in the other less than 1,500, the second being less than 1,350 feet. Even making liberal allowance for changes of level since their deposition, we can readily believe that the deposition of drift, assuming its subaqueous origin, began at the lower levels before the volcanic outburst, and did not reach the northern localities till later. The apparent haphazard occurrence of the ashes in Knox County may be readily explained by their preservation only in lagoons along the ancient Niobrara. When they fell on the land rains would soon wash them away, and when in the main stream they would be swept onward and mixed with other sediments. The idea that they fell in ponds is further supported by the occurrence of the fossiliferous clay immediately below.

If we accept the more commonly received hypothesis that the till is the product of land ice, we may suppose that the older ice sheet advanced to the altitude of West Point from the Des Moines Valley, while the occupation of the Dakota Valley was later. Or we may sup-

NEAR VIEW OF VOLCANIC ASH STRATUM IN BLUFF ABOVE WEST POINT, NEBRASKA.

pose that the deposits were simply formed in bayous along the adjacent streams when they were flowing at high levels. It should not be forgotten, however, that it is by no means certain that the ash beds in different localities were deposited at the same time.

There is little loess upon the surface of the drift for several miles east of the Bazile, and erosion has cut this bed of gravel into abrupt knolls, which are very conspicuous. Near the Bazile and along How Creek erosion has also sapped the sandy formation so that the gravel-topped knobs have sunk bodily toward the streams.

Farther east, about 5 miles southeast of Santee Agency, the loess begins to so cover the drift that it is almost entirely hidden, except along the face of the bluffs toward the Missouri. Its continued gravelly character is well shown southwest of Herrick, about what is called the Devils Nest, a descriptive name for two or three very deep ravines excavated through the loess, drift, and Tertiary sands to a depth of over 100 feet. One of the most complete sections found is at or near the northwest corner of T. 32 N., R. 3 W. The whole section, from the summit of an adjacent hill, is as follows:

Section near the northwest corner of T. 32 N., R. 3 W.

	Feet.	In.
Slope, probably loess, though bowlders were found near the summit	50	0
Loess exposed	4	0
Stratified sand, gravel, and bowlderets of granite, greenstone, etc	0	8–18
Reddish, loamy, joint clay containing northern pebbles	15	0
Fine white sand, stratified	7	0
Reddish clay and rusty sand	4	0
Stratified lead colored clay	1½–2	0
Fine sand	15	0
Wet efflorescent clay	0	8–10
Sand	4	0
Clayey sand	3–4	0
Whitish marl alternating with layers of sand	50	0

In another section several rods west, below the loess, which was about on a level with a corresponding point in the preceding section, the strata were as follows:

Section several rods west of the preceding.

	Feet.	In.
Stratified gravel and bowlders, about four coarse layers with fine sand alternating, all sorts of northern erratics present	4½	0
Laminated loamy clay with two layers of pebbles	3	0
Fine gray sand passing into 2 feet of chalky clay	16	0
Grayish checky clay, stratified, with fossil planorbis and other fresh-water shells, and a few small pebbles	3	0
Sand containing fragments of chalkstone and of large bones and teeth	1	0
Chalky clay	6	0

A general section showing several exposures noted is given in fig. 16.

The gravelly drift is also made prominent by its capping long spurs extending northward along the northern edge of the loess table-land.

The tops of these are nearly in a line, about 390 feet above the r while the gravelly layer back under the loess is 450 to 475 feet. T appear like the remnants of a gravel-topped terrace, but as they l no counterpart elsewl it seems probable they, like the lower along the Bazile, l been let down fron original high positio the escape of fine tiary sand from ben them. Farther e along Weigand and ver creeks, gravelly races again appear still lower level; tl though containing same material as higher deposits alr described, are doub a rearrangement of t as terraces of th streams. The gra drift underlain by s appears to have onc tended as a sheet the whole region of Beaver and the Bows cupying the most Cedar County. It been affected by ero so much that it is now continuous ex along the divide.

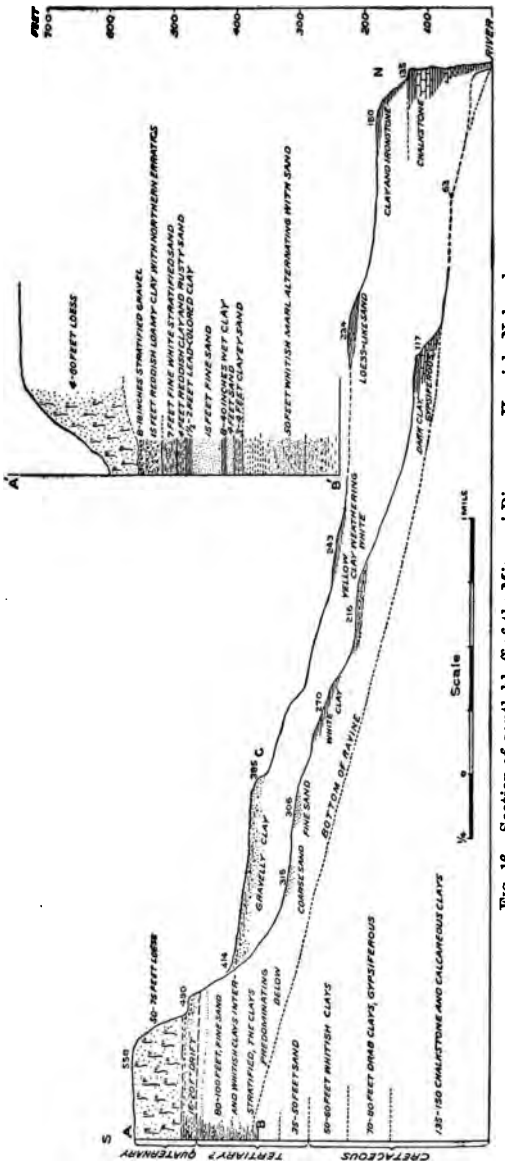


FIG. 16.—Section of south bluff of the Missouri River near Herriok, Nebraska.

In a high hill 3 miles southeast of Y ton the summit of drift is less than 300 above the river, shows much sand in nection with it. In bluffs south of St. He the chalkstone rises 225 feet above the river and only a few bowl and pebbles appear upon it, below the loess, which there rises onl feet higher. At several points along the West Bow incomplete e sures show the drift thin and with frequent bowlders, resting unifor *on sand.* Curlew Spring, a copious spring or system of springs abo

BLUFF ABOVE FLORENCE, NEBRASKA, SHOWING ASH STRATUM.

miles south of Hartington, comes from the underlying sand, as does also a magnificent spring 4 miles west of Coleridge.

The sand below the drift, which is there nearly pure coarse stratified gravel, is finely shown in a cut 2½ miles north of Coleridge. It is pure and stratified in thin layers (Pl. XIII).

In a cut near Hartington, Nebraska, the drift was found resting upon a calcareous marl much resembling loess, and differing from it principally in its more distinctly stratified character. It furnished numerous specimens of fresh-water shells, which Prof. R. E. Call, to whom they have been submitted, has identified as follows:

Valvata tricarinata Say.
Succinea obliqua Say.
Gyraulus parvus Say.
Sphærium striatinum Lam.
Limnophysa decidiosa Say.
Limnophysa palustris [?], imperfect specimen.

Two or 3 miles east of Hartington a similar exposure was noticed in the bank of the East Bow. It seems probable that this is a late Tertiary deposit, probably belonging to the Equus beds of Cope.

The gravelly character of the drift continues south along its western limit as far at least as Creighton. East of that place, at an elevation of about 110 feet above the station, abundant traces of gravel are found by the roadside through a vertical distance of about 10 feet, above which the loess begins to appear. About 5½ miles east of Creighton a well freshly bored was noticed at the place of Mr. D. C. Cleveland, who kindly gave me several facts, not only in regard to his own well but in regard to those in the vicinity. This well was on the general level, 150 feet above Creighton, or 1,767 above the sea. A section of the well was nearly as follows: Seventy or 75 feet of loess-like clay with no pebbles above but with numerous calcareous concretions, a few pebbles below, passing into pure gravel, which extended down to a depth of 80 feet. Below the gravel was 10 feet of fine sand. This, he told me, was the common experience in wells of that vicinity. He had the impression that water was found nearly upon a level. A well half a mile west, starting about 30 feet lower, is about 125 or 130 feet deep and has 22 feet of water. In it there was only about 40 feet of the loess-like clay. In digging wells blue clay is not usually found, but in a well about 2 miles southeast, in a valley, 2 or 3 feet of blue clay was found above sand. Whether the blue clay contained pebbles or not he was unable to say. A well bored half a mile south, 100 feet deep, was nearly or quite all in sand. A northwest-southeast line passing about half a mile south of his place marks the northern boundary of a sandy region—the ancient channel passing by Creighton and Plainview to the north branch of the Elkhorn. This line seems part of the eastern boundary of the region supplied with water from the Pliocene sands. No further trace of drift was found till we came to the upper branches of the Bow in the southern part of T. 33 N., R. 1 W., where

the drift appears again as a gravelly terrace in the sides of the principal valleys. An old resident of the region remarked that the bowlders were mostly upon the surface. This was found to agree with our observations. Because of the unusual variations of the barometer the elevation of the drift at this point was not well determined, but from its relation to the general level of the country we judge it somewhat lower than near Creighton. About Hartington and Coleridge beds of gravel and bowlders appear up to an altitude of about 1,760 feet. This elevation was noticed in the sides of the valley near Coleridge. The elevation in a high range of hills 4 miles southwest of it rises to about 1,625 feet. In the wells about Hartington, according to the testimony of Mr. Reed, a well digger of the place, the wells are from 36 to 50 feet in depth, those upon the lower land being shallower. The water is found apparently upon a level. After passing through soil and several feet of silt and alluvium (this I judge to be the case from a railroad cut near town) white clay in layers is struck and below that plastering sand with pebbles in which specimens of petrified wood are frequently found. At Coleridge, as stated by Mr. Miller, of that place, wells are 35 to 40 feet in depth, passing through about 6 feet of black soil, 17 feet of clay of loess-like character, 3 feet of sand, and then clay again.

At Concord there is 4 feet of soil, then sand without the clay. Passing eastward from Coleridge, bowlders and pebbles are found to the eastern edge of the valley upon the terrace-like tables in the valley before described, underneath the capping of silt, but after leaving the valley no pebbles are seen until the valley of the East Bow is crossed. They then appear upon a few hillsides about the same distance below the highest hilltops as before. No more drift is noticed until we reach the Missouri at Ponca. Everything is covered with loess, which in the valleys has washed down or crept down from its original higher position. In the bluffs south of Vermilion the following section was observed:

Section of the bluffs south of Vermilion, South Dakota.

	Feet.
Loess with a clayey stratum about 10 feet above its base, and below a few layers of small pebbles interspersed, the base itself a distinct horizontal line	40–50
Bowlders and stratified gravel with clayey patches	3–4
Coarse orange-colored sand, light above, with reddish streaks	3–4
Fine white sand with yellowish streaks	5–6
Cretacous clays of the Benton group	95
Level of the Missouri.	

At the landing at Ponca another fine exposure was found, for which we had time to make only a hasty estimate, as follows:

Section at the landing at Ponca, Nebraska.

	Feet.	In.
Loess with several feet of sand below	50	0
"Chalk rock," exposed	10	0
"Chalk rock," not clearly exposed	40	0
Dark shale	10	0
Dark shale or hard clay with yellow layers	4	0
Coal		8–10
Rusty sandstone	4	0

BASE OF DRIFT NEAR COLERIDGE, NEBRASKA.

Along the Missouri, south of Ponca, drift exposures are not prominent. The older formations rise high and are capped with high bluffs of loess. Southwest along the railroad in Dakota County the cuts exposing drift in any form are scarcely noticeable. Clusters of bowlders are reported along the valley of Elk Creek. Near Wakefield a few bowlderets and northern pebbles are sometimes struck in deep wells, but generally south of the watershed bounding the immediate valley of the Missouri—that is, including the short streams flowing directly toward it—the whole surface of the country is so deeply buried with loess that northern erratics are almost unknown. Even experienced well diggers will sometimes aver that none are to be found.

More recently the opening of the Pacific Short Line from Sioux City to O'Neil, Nebraska, has afforded much better opportunities for

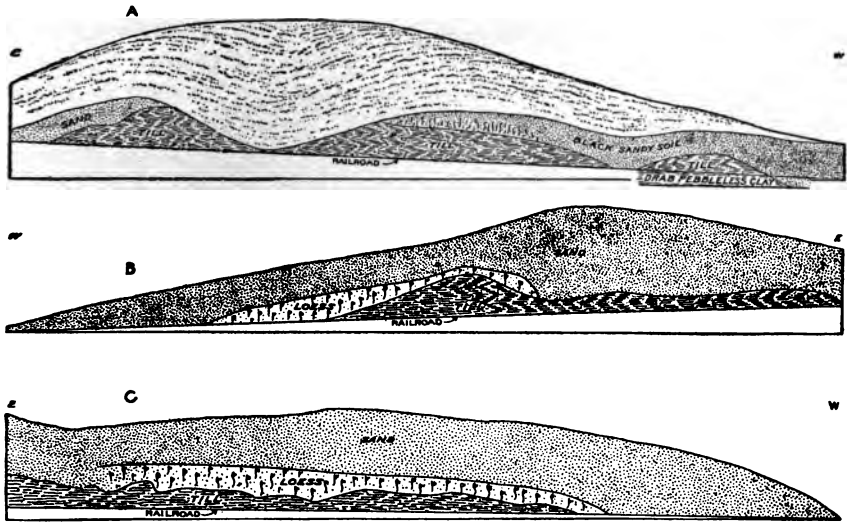


FIG. 17.—First railroad cut east of Osmond, Nebraska. Scale same as on fig. 18.

examining the surface formations of this region. It is particularly instructive between Randolph and Osmond, where it crosses the divide between the west branch of the Logan and the north branch of the Elkhorn. West of Osmond no traces of northern erratics are found except a few pebbles, which are likely to have washed from the hills immediately east. The universal subsoil is sand, which for the most part shows the shaping action of the wind. It occasionally contains grains as large as one-fourth inch long, usually of a light feldspar. In the valleys pebbles, mostly of quartz of different colors and well rounded, and unlike those commonly found in the drift, are found.

The valley of the North Elkhorn, in which Osmond lies, is bounded on the east by hills more abrupt and higher than those on the west, and bowlders appear on their sides. The difference in altitude is doubtless due to erosion which has taken place since the deposition of

the drift. About 1 mile east of Osmond, and about 25 feet higher than the station, an exposure at the foot of a north slope showed typical yellow till with few pebbles, resting conformably upon a drab pebbleless clay at least 2 feet thick and exposed for 2 rods. The junction was even, horizontal, and abrupt. One passed completely into the other in less than 6 inches. The relations are shown in figs. 17 and 18. As the road rose along the east side of the valley the exposures of yellow till were found appearing regularly, usually with the upper surface rounded similar to the present surface, but not always corresponding, sometimes showing no correspondence. It is overlain by sand, loess, red loamy clay, or gray till, without trace of an old soil or distinct weathering. The ashy colors may perhaps indicate action of vegetation near water level, or in some cases more likely more direct derivation from the drab Cretaceous clays. The annexed figures show the relations of surfaces of the different formations.

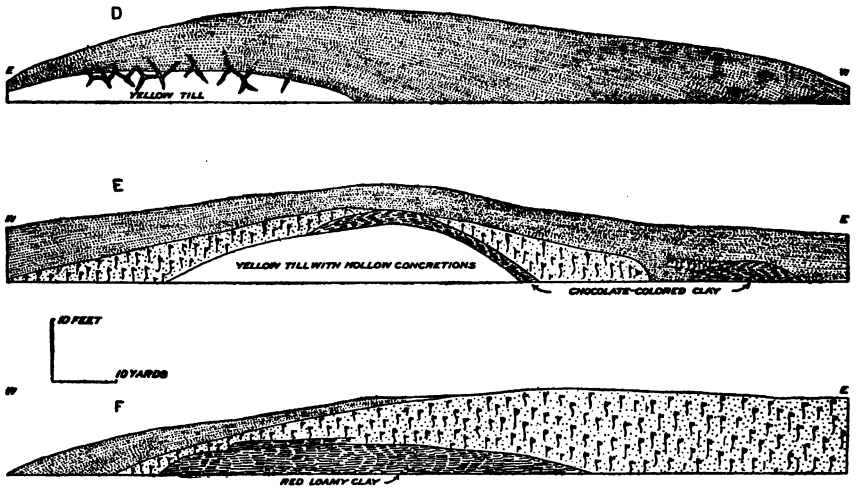


FIG. 18.—Cuts east of Osmond, Nebraska.

About 150 feet above Osmond, on the west slope of the divide, a flat area covering perhaps a square mile was noticed. From the cuts along its west and north sides it seemed to be underlain by till and topped with 20 to 30 feet of loess and sand. These last seem to intermingle indiscriminately. In some places they are interstratified. The adjoining figures sufficiently illustrate their relations. The higher ridges, rising 50 to 75 feet higher than this flat, are probably composed entirely of these materials. They usually extend northwest to southeast.

Besides the formations already mentioned there is also found a chocolate-colored variety of the reddish loam, which is darker than the usual shade of the loam. It is usually found in patches upon the latter at higher levels. The gray, pebbly clay which was noted nearly filling one of the cuts on the west side of the till flat also shows more of a *chocolate* shade above.

One very remarkable feature of the clays shown at higher levels, in places very conspicuously, is the occurrence of great cracks like ordinary mud cracks in their general features and arrangement, but on a vastly larger scale. They are frequently 8 to 12 inches wide at the surface of the clay and penetrate it 4 to 6 feet. They are filled with sand from the deposit above. The sand in the cracks and that directly above them for 2 or 3 feet is unstratified, while the surrounding sand is distinctly and horizontally stratified. The sand is not in the least mixed with the clay in the sides of the cracks. The cracks penetrate yellow and chocolate or gray clays alike.

Several inferences may be fairly drawn from these phenomena: (1) The till was very wet when first exposed to the air; (2) it became very dry before the advent of the sand; (3) the chocolate clays and yellow clays were deposited about the same time as the clay and have passed through similar circumstances; (4) we could not well imagine stronger proof of the subærial deposition of the sand. Its horizontally stratified character does not indicate deposition in water.

Very limited exposures of pebbly clay have been found, however, about 12 miles north of Winside, and as far southeast, along Humbug Creek; also at a few points along the north branch of the Elkhorn, which have been mentioned elsewhere. Bowlders have been reported also as found along Plum Creek and Rock Creek, in Cuming County. Four or 5 miles northwest of West Point are two bends in the Elkhorn which cut deeply into its western bank. The upper one is the more complete. It displays the formation from the general level of the country down to the level of the stream, as follows:

Section on the Elkhorn 4 or 5 miles northwest of West Point, Nebraska.

	Feet.	In.
Loess, its lower surface horizontal and distinct; just above it 3 or 4 feet of compact clayey layer, with a stratum in its upper portion about 8 inches thick blotched with blackish, doubtless due to carbonaceous matter	50	0
Red clay, its upper half more loamy, homogeneous and without pebbles. The first 6 feet above its base presents four horizontal bands of checky clay 8 to 10 inches thick, and the next 6 feet above four more thin ones of similar character. These all alternate with sandy or loamy layers. Pebbles of red quartzite are occasionally found in thin, short layers, which occur as high as 20 feet from the base	45	0
Whitish clay	4	0
White clay or marl	2	0
These last two pass laterally into a stratum of volcanic ashes a few rods farther west, away from the river. This volcanic ash bed is horizontally stratified in very thin layers, its texture as fine as flour; its color, for the most part grayish white with yellowish streaks in its upper portion.		
Muddy sand, passing laterally into obliquely stratified sand with bowlders below	2½	0
Fine greenish clay, thicker at some points		6
Yellow till	4	0
Compact blue till	5	0
Level of the river.		

In the lower bend the top of the till is scarcely exposed above the surface of the water. No distinct trace of the ash stratum has been found there, and the horizontal base of the loess, which is very distinctly exposed, showing above the carbonaceous layer, is only about 50 feet above the stream.

At the town of West Point, in a deep clay pit near the summit of a hill northeast of town, a combined section is as follows:

Combined section at West Point, Nebraska.

	Feet.
Loess, sandy above, showing wind-drift structure	30
Dark carbonaceous clay with numerous fragments of shrubs and roots in its upper portion	3–4
Reddish joint clay without pebbles, yellow and laminated above	4–5

On the hillside west, 40 to 50 feet below the bottom of the pit, drift pebbles are scattered.

Perhaps 15 feet lower on the hillside, by the schoolhouse, is an exposure showing about 15 feet reddish and yellow till, with a few bowlders. The western side of its lower portion slopes abruptly and is overlain for several feet by horizontally stratified sand, which probably corresponds to the sand in the lower part of the high terrace along the Elkhorn farther south. The bottom of this exposure is estimated to be about 30 feet above the railroad, or 45 feet above the Elkhorn.

Where the railroad crosses the west branch of Maple Creek, in the northern part of Colfax County, the following section is exposed:

Section in Colfax County, Nebraska.

	Feet.
Loess surrounding a core of yellow till which is 15 feet in height above the bottom of the cut. This above contains many chalky seams, and exhibits reddish clay and sand upon its slope	25
Eight feet lower the base of the yellow till is exposed in the side of a bank near by and below it.	
Drab-colored pebbly clay and fine stratified sand	2
Clay	1½
Fine stratified sand	3

Between Tekamah and Oakland various cuts along the railroad expose the loess, "old soil," as its dark lower portion is frequently called, and red clay down to the till.

About a mile above Florence a fine section reaching down to the surface of the Missouri may be made by combining two great exposures which are not far apart. From the top of the till west it is as follows:

Section of bluff near Florence, Nebraska.

	Feet.
Timbered slope	50
Loess exposed, lower half considerably darker than above. No dark stratum near base and red clay lacking	35
Till, yellow above, but mostly blue. In a few places small pockets, containing stratified gravel and a few large ones below filled with very fine yellow compact massive sand	75
Level of the river.	

About a half mile north of the last a very different section was finely exposed by excavating for gravel at the time of the building of the Omaha waterworks near Florence. The following is the section (see Pl. XII):

Section half mile north of the last.

	Feet.
Slope	10–20
Loess	25–30
Stratified clayey loam, yellow, with many calcareous concretions	7
Volcanic dust like that found farther west, except stained with rust	1½
Yellow clayey loam, slightly stratified	5
Fine gray sand	½
Coarse sand and pebbles obliquely stratified, mostly of northern origin	20
Unexposed, probably part blue till, judging from sections on the opposite side of the river	15–20
Level of water in the Missouri.	

From many sections found along the Platte west of Fremont the following is chosen as probably the most instructive. It is found near the southern end of the old bridge southwest from town.

Section west of Fremont, Nebraska.

	Feet.	In.
Loess, the dark line 3 feet above its base appearing only as thin wavy streaks	30	0
Red clay, passing into drab and rusty below	11	0
Whitish clay with many chalky concretions and numerous pebbles, some of them scratched. This deposit ends abruptly at one end and at the other tapers out	2	0
Similar reddish and drab clay with pebbles, but with few if any bowlders	22	0
Light greenish clay, blotched with white, extending horizontally at least a rod. Its ends are hidden	1	2
Reddish clay, passing below into 20 feet till which is yellowish above, but the blue color rises in places near the top	11	0
Level of the river.		

Farther east, near the present bridge, a layer of coarse sand obliquely stratified replaces the blue till to the height of 10 or 12 feet above the river. This is probably a portion of the sandy substratum found in the high terrace developed along the north side of the Platte. Farther west, southeast of Timberville, the strata are the same as before given, except that the till is not exposed and the base of the till is 30 feet higher, and between it and the red clay is a stratum of blackish mucky clay 4½ feet thick. In the bluffs south of Linwood bowlders and pebbles abound at a level lying between 50 and 115 feet above the valley to the north. At the lower level several feet of fine stratified sand appears and probably rises considerably higher. Northwest of Schuyler, on the slope of a high bluff overlooking Shell Creek and the Platte Valley, many northern pebbles are found at the height of 175 to 225 feet above the latter. Bowlders abound upon the hillsides in a strip from 10 to 12 miles wide, extending along the western side of Saunders and Lancaster counties nearly to the southwest corner of the latter.

In the railroad cuts between Denton and Berks, southeast of Lincoln,

there are abundant exposures of the drift. About 3 miles east of the latter station the following section is found:

Section southeast of Berks, Nebraska.

	Feet.
Slope from the top of one of the highest hills, which was strewn abundantly with bowlders, to the edge of a deep cut	70
Yellow till, mostly exposed, with a few bowlders	30
A few rods southwest of this, in another cut overlapping, is found—	
Fine sand obliquely stratified	15

The yellow till shows obscure traces of stratification in its lower portion in the form of layers of pebbles, and banded arrangements of colors parallel with its lower surface. The sand, on the other hand, bears marks of erosion. Its strata end abruptly against the till, but no trace of distortion in them was discovered. Their eroded surface slopes abruptly toward the east. In lower cuts on the east the fine sand occurs under the drift, sometimes with greenish clay interstratified with its upper layer (see fig. 15).

About 3 miles south of Pleasant Hill, about 20 feet below the general level, the recent digging of a well furnished unusually favorable opportunity for obtaining the following section:

Section near Pleasant Hill, Nebraska.

	Feet.
Black soil	2½
Yellowish clay, passing into the next	6
Reddish clay	6
Lighter clay, distinctly separated from, but conformable with, the next	22
Fine stratified sand, quite compact. Two red quartzite bowlders were found on its upper surface	6
Sand interstratified with clayey layers	8
Niobrara chalkstone.	

Numerous small bowlders of red quartzite, greenstone, etc., are found in the deeper ravines in that vicinity on the same level with their occurrence in the well. The chalkstone also crops out farther east along Turkey Creek, and underneath it is said to occur a dark carbonaceous layer, probably of the Benton group.

About 8 miles southwest of Milford, in a deep bend in the West Blue, which cuts into its southern bank, the following interesting section[1] was found:

Section 8 miles southwest of Milford, Nebraska.

	Feet.
Soil	2
Red gritty loam	6
Stratified loamy clay with thin strata, rounded white quartz pebbles, passing into the next	9
Clayey gravel, with a few bowlders of red quartzite, passing into the next	3
Stratified loamy clay, with streaks of pebbles	15
Light-gray siliceous earth, volcanic ashes very evenly laminated	1–6

[1] This section was published in Science, 1887.

Section 8 miles southwest of Milford, Nebraska—Continued.

	Feet.
Clay, darker above, below passing into the next	1½
Gray sand, with thin sheets of clay 6 to 12 inches apart	5
Coarse sand, with pebbles and bowlders of various sorts resting upon an uneven surface below	1
Hard greenish joint clay	6
Slope	8
Water of the West Blue.	

A few rods distant a less complete but similar section shows the volcanic ash layer 5 feet thick, and it appears along the sides of a ravine for several rods.

The deeper draws west of the Big Blue, in southern Seward County, frequently show beds of gravel corresponding to the upper portion of this section in which the pebbles are mostly, if not entirely, of western origin. Incomplete exposures of drift exhibiting weathered till are found in favorable circumstances over most of the region east of the bowldery strip outlined above, but the deep deposit of loess renders their occurrence quite infrequent. Near the Missouri, and at some points quite remote, the loess is found to rest upon the older rocks without traces of drift between.

THE DRIFT IN SOUTH DAKOTA.

In South Dakota there is a limited area outside the moraine which is occupied with loess. We proceed to consider the drift underneath it.

At Vermilion there is a terrace which rises about 80 feet above the flood plain of the Missouri. The southern edge of this terrace extends nearly due east from this place to Brule Creek. The structure of the terrace is unusually well shown in cuts at Vermilion. The mass of it is composed of a pebbly clay, the upper portion of which is quite homogeneous and of a yellowish color. In this were noticed certain levels several feet apart, in which bowlders were more abundant. Below the pebble clay is less homogeneous, showing pockets of sand, some stratified obliquely. The prevalent color of the whole is blue. No exposures were found lower than 20 feet above the river. Wells in the town show gravel 125 to 160 feet below the surface. The upper surface of the pebble clay was evidently eroded before the mantle of loess which covers it was put on. This loess is not considered of the same age as the more extensive deposit, but is probably simply a deposit of silt in comparatively recent times. Upon this terrace are frequently found basins resembling those upon till. The upper plain of this terrace surface extends north to the moraine and east to Brule Creek at a very uniform level. The exposures along the Vermilion River indicate that the same general characters prevail throughout.

A study of the cuts along the railroad between Beresford and Calliope indicates that the drift here, instead of being gravelly, as in northern Nebraska, is for the most part clayey, the stony ingredients, including sand, forming perhaps less than 30 per cent. Between the

moraine and Brule Creek, in shallow cuts, yellow pebble clay and loess-like clay are interstratified, perhaps by wash from loess exposures above. In the cuts near the side of the long north-south valleys running into Brule Creek from the north the pebble clay below shows a washed surface, and sometimes a thin layer of gravel, while sand prevails in the end of the cut toward the valley. Everywhere at low levels (and there are no deep cuts very high above the bottom of the valleys) the correspondence of the drift with the present surface of the country is clearly seen. In the summit cut, between Alcester and Calliope, there are exposed loess and an irregular layer of reddish clay lying above the yellow pebble clay which in some places show 5 feet or more. A few small yellow sand pockets were observed with stratified gravel in their upper portions. This was at an altitude of 90 feet above Alcester. In a cut about 25 feet in depth 2 miles west of Calliope, on the south side of the valley of a small stream and about 100 feet above the Big Sioux, the pebble clay was exposed to such depth as to exhibit a decided bluish cast in its lower portion, although the upper 15 or 20 feet showed the usual yellowish appearance. As in the cuts near Vermilion, the yellow passes insensibly into the bluish pebble clay. Here the yellow banded seams, dividing the blue till into polyhedral masses, were finely shown. Another peculiar feature of the pebble clay in this cut was the existence of cracks which resemble immense mud cracks, descending 3 or 4 feet from the surface and widening above to 4 or 5 inches. These cracks were filled with a coarse yellow sand. With this exception no deposits of sand were found in the cut. Similar cracks were found to be more numerous in some of the cuts farther west. In this same cut the pebble clay was capped with loess, an eroded surface with several inches of gravel and occasional bowlders separating them. Another feature was well shown in this cut which occurs not infrequently elsewhere, especially at lower levels in the till. These were patches of lead-colored clay, free from pebbles and resembling the Cretaceous clay in texture and color. These are often 2 or 3 feet thick and from 4 to 5 feet to a rod in width. The most rational explanation that has presented itself is that the core of the hill is of such clay, and that while the pebble clay was forming this became mixed, either en masse by the thrust of ice or by becoming plastic it flowed down on the already deposited drift. Different cases may have been formed in these different ways.

Near the Big Sioux west of Calliope the bottom of the drift, as marked by an exposure of travertine rock, is about 65 feet above the stream, while its top is 125 feet, and has the appearance of the edge of a terrace. Farther north, west of Eden, the top of the drift near the Big Sioux is about 160 feet above the Big Sioux. Along the Big Sioux north of Eden is a high terrace of stratified gravel about 65 feet above the Big Sioux, and in a slide just west the Tertiary (?) deposits, composed of lead-colored shale and sand, rise about 50 feet, above which

comes first about 4 feet of fine sand, then pebbles and bowlders. The drift continues from that upward to 117 feet upon a spur extending from higher land farther west.

Along the Dakota side of the Big Sioux below Beloit, Iowa, pre-Glacial deposits are found finely exposed at several points. They are especially conspicuous where the stream has encroached upon the highland in close proximity to the moraine. Since the formation of the bowldery terrace which slopes down from the plain about Canton to the mouth of Rock River, the stream has found the pre-Glacial beds so easily corraded that it has slipped off from the terrace and cut down from 70 to 80 feet below it.

On or near sec. 18, T. 97, R. 48, the Big Sioux has encroached upon an unusually high bank on the south. About 250 feet above the stream is a terrace corresponding in height to the upland east of Beloit, but not so high by 50 feet as the till surface a mile or two west, which we consider a part of the moraine. The terrace is not fully exposed, and in some places the slidden bank makes the thickness of strata somewhat doubtful. Beginning at the top of this terrace, we have made out a section as follows:

Section on the Big Sioux River, 3½ miles east of Fairview, South Dakota.

	Feet.
Loess	6–10
Till with irregular stratified sand strata toward the bottom. The lower 20 feet is blue and almost free from pebbles. Possibly equivalent to the pebbleless clay east of Canton and Sioux Falls	100–110
Fine sand with large rusty concretions of upper portions and a few fragments of large pearly shells (Unios?). This stratum is of undetermined thickness and is doubtless a source of the very copious springs along the base of the bluff farther east which deposit travertine	20
Unexposed. Probably much of it is a pebbleless clay of Cretaceous age	110
Level of the Big Sioux, about 1,200 feet above the sea.	

Half a mile farther east is exposed 5 to 6 feet of black clay capped with a layer of shaly sandstone which passes below the water of the Big Sioux, forming slight rapids. This dark clay resembles closely the Benton clay as seen opposite Vermilion, but no fossils were found to decide the point. It is probably a rearrangement of this clay, or possibly a portion of the original deposit itself, which has been successfully used in making ornamental brick near Fairview.

There is little doubt that the clay and sand near Eden, South Dakota, and those shown in the cuts east of Canton, also north of Sioux City, belong to the same formation with those appearing in this section. The sand may be of very late Tertiary age.

Along the Big Sioux between the falls and Brandon the drift abounds in gravel and bowlderets, the latter being largely formed of red quartzite. From near the level of the bottom lands above the falls there extends a well-marked terrace down the river, sometimes upon one side of the river and sometimes upon the other. In its upper por-

tion it is composed of gravel, which is coarse above. Extensive exposures are found along the railroad. Its height above the river 2 miles west of Brandon, according to railroad levels, is about 80 feet. Near the northwest corner of T. 101, R. 49, are high hills, composed almost entirely of gravel, forming a ridge parallel with the stream and rising in their highest portion 210 feet above it and about 20 feet higher than the gentle slope which rises from it southward toward the moraine. In this the coarser material seems to be above. An exposure about 50 feet below the summit showed coarse plastering sand.

About the town of Sioux Falls are numerous exposures, some of which are shown in figs. 22–26. In general they show in higher places thin deposits of loess, as though deposited along the stream when flowing at higher altitudes. Below this, in some places, comes yellow pebble clay, usually with the washed surface. In one case a confused mass of bowlders is found at this horizon, in others a dark layer 1 to 3 feet, as though an old soil or mud bed formed in the stream. This is usually from 30 to 40 feet above the level of the Milwaukee station. In a few cases this seems to be overlain by yellow pebble clay instead of loess.

In the cuts northeast of Sioux Falls, along the line of the Illinois Central Railroad, there is an exposure of deposits similar to those noted east of Canton. They are as follows:

Section northeast of Sioux Falls, South Dakota.

	Feet.
Loose loess	5–6
Drab, checky yellowish clay. A few black siliceous pebbles, more numerous below, with some white pebbles and small bowlders of red quartzite	6–7
Dark soil-like clay, checked with white concretions of black pebbles, some of them trap and flat	3
Similar, but lighter, containing calcareous concretions and black pebbles. Coarser bowlders come in at the top horizontally. Three rotten granite bowlders were found, though there were many others which were solid	5
Gravel, with numerous bowlders in the upper portions	10–12
A drab plastic clay with few pebbles, weathering a creamy ocher (older till)	5–6

The top of the last stratum is very little higher than the Chicago and Northwestern station. The gravel stratum is quite variable in thickness, and the pebbly clay above shows a dark stratum of clay which has the thickness and general appearance of a soil, but in other cases is not present.

About Garretson and north for 2 or 3 miles is a small driftless area, which is of peculiar character. The bed rock is Sioux quartzite, much fissured, and traversed with channels which are 60 or more feet in depth. The Split Rock, the principal stream, seems not to have cut to the bottom of some of the old channels. Upon this rests a loess-like loam, in places passing into fine sand. Its thickness has not been determined, partly because it is not easily differentiated from the loess, which is probably of more recent date. In a careful examination of both sides of the Split Rock for 1½ or 2 miles north of Garretson no

case of worn surface or northern erratics was found, except a very few scattered over the surface of the underlying rock, which may easily have washed from north of the area. This feature is in marked contrast with the surface of the rock a little west of the Palisades, where the loam is absent and the rock is worn and grooved by the action of the ice. The thickness of the pre-Glacial loam at Garretson has not been clearly determined, but a thin edge of clayey gravel is found overlapping the loam a little east of Garretson, and a stony deposit of northern sand and bowldery clay is observed upon the summit of several knobs which may be detached remnants of stream beds or bowldery terraces and which rise 125 or 150 feet above Garretson, which place is, by railroad level, 1,496 feet above the sea. The connection has not been traced, but it seems probable that this stony stratum corresponds with the bowldery layer at the bottom of the till east of Canton, and that it marks the level of the discharge of water along the east edge of the Dakota lobe at a time somewhat antedating the occupation of the outer moraine. If this, however, is correct, the difference in the level and the consequent rapid currents southward would account for the coarser material. This, it will be observed, would correspond to the earlier deposition of till east of Canton. A heavy gravel deposit east of Sioux Falls would correlate well with this same deposit.

In the loam capping the high terrace just east of the Big Sioux, above the falls and opposite the city of Sioux Falls, there were found in 1894 two tusks, three or four teeth, and fragments of bones of a large mammoth. The tusks were over 6 inches through at the base, and the portions remaining were over 7 feet long and much curved. This terrace rises to about 60 feet above the present stream, and was probably the flood plain of the river during the earlier occupation of the outer moraine. At a lower level large bones, supposed to be of a mastodon, were reported at an earlier date. Probably from the lower level also came the skull of a musk ox now in the museum of the University of South Dakota.

A few miles north of Clark, in Clark County, outside of the moraine, beds containing wood and fresh-water shells were struck, in digging wells, 25 to 30 feet below the surface. This is the only case which seems to correspond with the forest beds reported from eastern Iowa and Illinois, and these are not certainly known to be covered by till.

THE DRIFT IN IOWA.

In a section opposite Fairview drift was found to a height of 240 feet above the stream. The Big Sioux has there worn deeply into the highlands on the east side. An extensive slide, probably caused by a softening of the Cretaceous or Tertiary clays below, has exposed about 50 feet of pebble clay, the upper portion of which is yellow, the lower blue, exhibiting the selenite seams, with the yellow layers adjacent, like those shown in the cut west of Calliope and already described.

From a series of cuts between the Big Sioux east of Canton and Inwood, Iowa, as well as a careful study of slopes and reports from a few wells, we construct the following section:

Section on Big Sioux, east of Canton, Iowa.

	Feet.
Loess, with an undetermined thickness of till probably occupying the lower portion. From some reports as well as from the cuts it would appear that nearly or all of it was loess, but from the distribution of water and the reports of other well-diggers it seems that half or two-thirds of it is till	90–100
Gravelly clay in places. This seems to be the same which is conspicuously developed as a shoulder along the hillsides next the Big Sioux farther west	10–20
Pebbleless loamy clay which weathers a creamy yellow (older till?)	50
A fine stratified sand without gravel, but no northern erratics. This sand probably corresponds to the sand west of Fairview. It is water bearing, furnishing a spring in a railroad cut	18–20
Unexposed, probably Cretaceous	60–75

Level of Big Sioux, 1,227 feet.

East of Kruger's mill, back of a terrace about 50 feet in height, the drift appears on the south side of a small stream showing a section, beginning about 108 feet above the stream, as follows:

Section east of Kruger's mill.

	Feet.
Reddish pebbly clay with some sand	9–10
Stratified sand, with sheets of clay obliquely set, and from a half inch to 6 inches thick	24
Blue till with an irregular surface above	5–6

Higher than this section the slope shows pebbles to a height of 180 feet, where bowlders are more common. North of the small stream, along what appears to be a much-eroded terrace, bowlders and gravel occur to the height of 125 feet, above which there is 30 feet of loess.

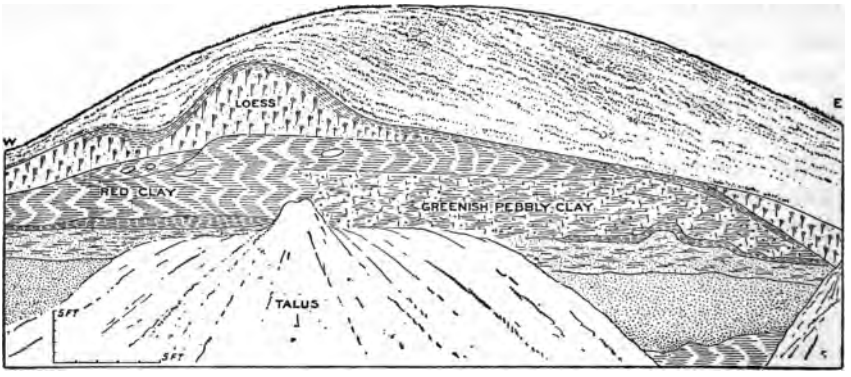


FIG. 19.—Sandpit section east of McCook, South Dakota.

Three or 4 miles west of Larchwood shallow wells show 5 to 10 feet of loess, below which comes yellow pebble clay or till. This seems to be the prevailing character of the upland region of Iowa throughout Lyon County.

Seven or 8 miles northwest of Sioux City, about St. Onge's place, as mentioned by Dr. White in his report, and not far from the ranch of D. H. Talbot, are several exposures showing the more recent deposits overlying the Cretaceous Inoceramus limestone beds, which form a conspicuous shoulder along the bluffs for many miles. The higher level of the Cretaceous is about 140 feet above the Big Sioux. Above this lies a bed of waxy yellow clay with irregular upper surface. It seems to be derived from the weathering of the limestone on which it rests. Above this is a bed of gray sand, coarser below. This has been sought for plastering purposes in Sioux City. A sketch of one exposure is shown in fig. 19. In no case have I seen more that 12 feet exposed, but it is probably much thicker farther back. The sand passes above into a greenish joint clay without pebbles. Upon this rests a thin layer of reddish till containing the usual northern erratics, and just above comes the loess. All the exposures studied indicate that the clays and loess have been let down and distorted by the escape of the sand from below. A generalized section would be as follows:

Generalized section near Sioux City, Iowa.

	Feet.
Loess	50
Reddish till	3–5
Greenish joint clay without pebbles	2–5
Gray sand, clayey above, coarser below	7–12
Yellow waxy clay	5–?
Cretaceous No. 3	140

Level of Big Sioux.

About a mile northeast of the railroad bridge across the Big Sioux, near Riverside, are several sandpits. In one a large lenticular mass of till was found in the loess. This was described and figured in 1895.[1]

One mile above Sioux City, between the summit of Dakota Point and the river, the following section may be found:

Section 1 mile above Sioux City, Iowa.

	Feet.
Slope	25
Loess, exposed, with several feet at base darkly covered with carbonaceous matter	150
Yellow till with an uneven surface above, reddish and loamy	55

Low water in the Missouri.

About a mile farther up the river, at the base of the bluff, is an exposure of gravel about 60 yards in length and 15 to 20 feet in thickness. Its base is unexposed, but its upper surface, which is about 50 feet above the water in the Big Sioux, is a horizontal line, and the loess stratified below rests directly upon it. A remarkable feature in the gravel is the occurrence of three great bands of coarse gravel and cobblestones, alternating with finer material, which dip abruptly to the south through the whole height of the exposure. The dip above is about 18°, but gradually diminishes toward the base.

[1] Proc. Iowa Acad. Sci., Vol. II, pp. 20–23; also by H. F. Bain in Iowa Geol. Rept., Vol. V, p. 284.

A study of this locality, which is near Riverside Station, subsequent to extensive removal of the gravel revealed the following facts, some of them quite puzzling. At first view it seems a clear case of till between two beds of loess. The gravel shows a level surface for several rods, and at the south end it has been found to be at least 30 feet thick. At that depth water, probably on a level with the river, prevented further excavation. Above the gravel at the south end rises 50 to 75 feet of loess. In it were found a few shells of Limnæa and Sphærium, which have not been observed elsewhere in the loess of this region. The summit of the hill back rises about 130 feet above the river.

At the north end of the exposure and 100 yards from the last the section above the gravel is as follows:

Section near Riverside Station, Iowa.

	Feet.
Slope, loess	50
Loess, exposed	5–6
Reddish till, thinning and dropping to the south and running out in about 80 yards	18
Massive loess-like silt, containing *Succinea avara*, similar to those now living on the bluff back, blotched above with carbonaceous matter, with a few fragments of water plants (?)	6
Upper surface of the gravel somewhat interstratified with the silt, and containing the same Succinea.	

Within a quarter of a mile farther north the top of the Cretaceous is evenly exposed about 80 feet above the river, and above it fine sand with pebbly clay above rising to 90 to 190 feet, the beds resembling those already noted near Talbot's. The most plausible explanation suggested at present is, therefore, that the gravel pit shows a comparatively recent formation in the base of a high terrace, possibly corresponding to that south of Sioux City.[1]

At Missouri Valley, back of the brickyard, there is found the following section:

Section at Missouri Valley, Iowa.

	Feet.
Loess, exposed, with "charcoal streak" a few inches above the base pretty well developed for this region. This loess shows crevasses or slight cracks nearly vertical from top to bottom	90
Drift exposed mostly reddish clay, loamy above, more stony below, and passing into blue till below	40
Thirty feet above station.	

One to 1½ miles north of Council Bluffs are found three great sand pits in the side of the bluffs. They are known from their owners' names as Lawlor's, Clark's, and Cassady's sand banks, naming them in order beginning with the most northern. At Clark's bank we find the most complete exposure, although some of the members are bet-

[1] Compare also an explanation in Proc. Iowa Acad. Sci. (1895), Vol. II, pp. 20, 23.

ter represented in the other banks. The section at Clark's bank is as follows:

Section at Clark's sand bank, 1 to 1½ miles north of Council Bluffs, Iowa.

	Feet.
Loess, exposed, which is sandy below	20
Dark clayey loam	3–4
Coarse sand, obliquely stratified in thick layers, with a layer of clay 6 to 8 inches in thickness, interpolated 12 to 15 feet from the bottom	40
Gravel	5
Blue till, white pebbles	8–10
Unexposed, but probably mostly till (level of the lake)	25

At Lawlor's the sand is slightly consolidated in its upper layers, forming a sandstone a few inches thick. A row of angular blocks of clay appears in the sand 12 to 15 feet above the base. The gravel is found 8 feet thick, obliquely stratified, with layers 8 to 12 inches in thickness. The blue clay appears as before.

At Cassady's bank, 2 or 3 miles north of Council Bluffs, Iowa, we have the following section:

Section at Cassady's sand bank, 1 to 1½ miles north of Council Bluffs, Iowa.

	Feet.	In.
Slope	80	0
Loess, exposed	20	0
Clayey loess, with concretions	3–4	0
Sandy loess	3–4	0
Coarse sand, suitable for plastering, found in eight or nine layers 3 to 10 feet thick, all obliquely stratified, dipping toward the south, excepting one or two	45	0
Fine wet clay, uniform in thickness	1	3
Rusty, coarse sand with cobblestones below; some of the layers consolidated	10–12	0

Below the last number a copious spring comes out, which, probably like many others, marks the upper surface of the till.

From 4 to 5 miles north of Pacific Junction, along the base of the bluffs, are some remarkable exposures showing the base of the blue till. This is seen to extend horizontally for a mile or more, being exposed very distinctly. In the principal exposure the following section is found:

Section 4 miles north of Pacific Junction, Iowa.

	Feet.
Loess	15
Yellow, reddish, and loamy pebble clay	15
Slope, indicating much rusty sand	55
Consolidated sand	½
Clayey gravel in patches, with fine yellowish sand, and strips of yellow and blue till intermingled with them	12–15
Typical blue till, with its base very even and horizontal	3–5
Joint clay without pebbles, of a dark brownish gray, passing below, in its thickest portion, into reddish clay with horizontal bands of rounded concretions from 4 to 6 inches in diameter; its lowest surface very uneven	11–17
Light gray, fine, stratified sand, containing small globular concretions	9–10
Level of Missouri bottom lands.	

About 2 miles north of Pacific Junction the following section is exposed:

Section 2 miles north of Pacific Junction, Iowa.

	Feet.
Brownish clay, passing up into soil	3
Light-colored sandy marl, passing into marl below, and with black and white concretions above	3
Layer of chalky concretions with black interior	½
Very fine sand, obliquely stratified, passing abruptly below into the next	6
Coarse sand and small quartz pebbles	4

East of Pacific Junction, in a spur of the bluffs near Keg Creek, is a deep railroad cut with the following section:

Section near Keg Creek, Iowa.

	Feet.
Loess	50
Dark-reddish or chocolate-colored loam extending horizontally across the exposure	3–4
Yellow till, uneven above and with loess filling the depressions under the dark stratum, many chalky concretions above and large, irregular sand pockets below. Remains of a young mammoth was found in the base of the loess or top of till	20–25
Unexposed	4–5
Irregularly bedded limestone, Carboniferous	4

At the point of the bluff south of Pacific Junction 2 or 3 miles, at one of a series of copious springs, there is the following exposure of drift:

Exposure 2 miles south of Pacific Junction, Iowa.

	Feet.
Stratified gravel, somewhat consolidated	2–6
Dark blue till, resting directly upon the next	½–1
Gray limestone, which is striated in a direction S. 15° E. (mag.); this is about 20 feet above the bottom land	2

One-half mile farther south and 60 feet above the bottom land is another glaciated surface, several yards in extent, upon a layer of compact blue limestone about a foot thick, resting upon clay. Striæ are found upon its surface having the following directions: The deeper ones S. 18° E. and S. 26° E. There are also some S. 54° E. and S. 52° E., very distinct, and still smaller ones S. 70° E. About a rod east of the first locality striæ were found S. 14° E. and S. 8° E. There are now only a few inches of rusty sand resting on this surface, with the loess above.

In southwestern Iowa numerous exposures have been examined along the various railroads. It seems unnecessary to enter into details, but better to give only a general statement. As a rule, the loess shows four or five clayey layers, from a foot to a foot and a half in thickness at its base, with frequent traces of carbonaceous matter in its lower portion. Underneath this appears the red clay, first without and then with pebbles, passing below into till, which in some cases, as near Clarinda, is 40 feet or more thick.

The junction of the loess appears as a rule only in the higher cuts upon the summits separating the principal streams flowing into the Missouri. Lower cuts, which are the most common, present an eroded surface of till upon which the loess rests, with the red clay occasionally appearing between. Usually the surface of the drift is approximately parallel to the present surface of the country, its convexity usually being less. The till presents the same features which have been noticed elsewhere.

ELEVATIONS OF SURFACE OF DRIFT IN LOESS REGION.

These elevations, from the nature of the case, are less definite than some which have been given. For the most part they are of points where the loess and drift show their original relation to each other. They are in every case barometric. Those showing old soil or charcoal streaks are marked with an asterisk *); eroded surface under deep loess with an obelisk (†).

Elevations of surface of drift in loess region.

Locality.	Elevation above the Missouri.	Elevation above the sea.
	Feet.	*Feet.*
South of Niobrara	425–460	1,645–1,680
Devils Nest	450–475	1,650–1,680
East of Creighton	470	1,690
East of Osmond	(†)	1,700–1,760
East of Norfolk	415	1,620
Twelve miles north of Northside	415	1,620
Clarkson	530†	1,560
Five miles northwest of Schuyler	560	1,572
Near Linwood	390	1,400
Bone Creek, east of David City	510	1,595
Germantown	575	1,530
East of Milford	500	1,450
Berks	530–555	1,450–1,475
Eight miles southwest of Milford	555–580	1,475–1,500
South of Pleasant Hill	560	1,475
Four miles southeast of Yankton	255	1,440
South of St. Helena	150	1,320
Five miles northwest of Hartington	385	1,555
Five miles southwest of Hartington	450	1.610
West of Coleridge	590?	1,710?
Northeast of Emerson	260?	1,360?
Five miles northwest of West Point	380*	1,426
Southeast of Timberville	330*	1,340
Southwest of Fremont	270*	1,280

Elevations of surface of drift in loess region—Continued.

Locality.	Elevation above the Missouri.	Elevation above the sea.
	Feet.	*Feet.*
Cheney	475	1,400
Bennett	400	1,320
West of Syracuse	205	1,125
East of Syracuse	255	1,175
West of Larchwood, Iowa	225?	1,465?
West of Inwood, Iowa	235	1,450
East of Fairview, South Dakota	245	1,450
West of Eden	220?	1,400
East of Hawarden, Iowa	270	1,370
Opposite Vermilion, South Dakota	350	1,450
Seven miles northwest of Sioux City	175	1,280
Riverside Park, near Sioux City	95	1,200
Northwest of Tekamah, Nebraska	290	1310
Blair, Nebraska	190	1200
About 4 miles northwest of Florence	140*	1130
One mile north of Florence	75	1165
North of Council Bluffs, Iowa	75	1065
At Council Bluffs	70	1055
Five miles north of Pacific Junction	150	1110
West of Silver City	170	1160
East of Pacific Junction	50*	1000
South of Pacific Junction	100	1065
West of Plattsmouth Bridge	100*	1055
East of Sanborn	.....	1550
East of Marcus	.....	1560
Northwest of Manilla	.....	1475
West of Minden	225	1230
East of Minden	225	1230
West of Marne	335*	1350
West of Malvern	200	1150
Southeast of Malvern	125*	1075
West of Red Oak	185	1140
West of Valisca	275	1230
Southwest of Shenandoah	240	1154
East of Shenandoah (Page Center)	345	1265
East of Clarinda (New Market)	380*	1320

The elevations given from Iowa are mostly taken from the summits between important streams. The junction of the red clay and loess often lies considerably lower in the cuts adjacent to these.

RELATIONS OF DRIFT TO LOESS.

The relations of the drift to the loess vary in different localities. Prof. N. H. Winchell in his annual report for 1877 published observations indicating the gradual passage of loess into till in the southwestern part of Rock County, Minnesota. This would nearly correspond to what the writer has elsewhere described in sections where the till and loess are connected through the medium of the red clay. Where the upper surface of the latter is rendered indistinct by the absence of the "old soil" and the loamy and pebbleless character of the red clay the statement of Professor Winchell would be exactly realized. Such have been frequently found by the writer in southwestern Iowa, especially where deposits have been somewhat disintegrated by weathering or leaching. Nevertheless, that the normal relation, at least in the central portion of the region, is one of distinct division between the red clay and loess seems borne out by observations which have been recorded above. As has been found in numerous localities, the drift often has a very distinctly eroded surface, which is marked by its unevenness and by the presence upon it of an unusual number of pebbles and bowlders. This washed surface, so far as has been observed, is confined to lower elevations; in southwestern Iowa to within 100 feet above the present streams. It is uniformly found in cuts where the railroad passes through the spurs running into a valley. The surface of the drift is convex, but in less degree than that of the loess above. Another interesting relation is found in the cuts adjoining the more important streams. In such cases the drift loses, in a measure, its parallelism with the present surface or with that of the loess, and its culmination in any cut is usually toward the more important stream, as would naturally follow from the greater erosion of the loess on that side. This is found to hold true provided the important stream rises within the loess area.

THE "OLD SOIL" AND THE CHARCOAL STREAK.

Numerous references have been made to the carbonaceous matter between the loess and red clay. Where the deposits are well preserved at the junctions of these formations there is rarely an absence of carbonaceous matter. It is sometimes in the form of driftwood scattered in the clay, as in cuts southeast of Malvern, at West Point, and southeast of Timberville, Nebraska. More frequently it has the appearance of a dusky shading of the clay, usually for 3 or 4 feet just above the base of the loess. This is frequently true where the driftwood is found. The term "old soil" is properly applied to such exposures. Its color may often be well described as chocolate, though it is sometimes more like that of black loam. The carbonaceous matter is sometimes found in wavy streaks scattered through the clay, as though sparingly deposited with the embedding of the material. Angular fragments of charcoal are distributed in the same deposit, usually very sparsely, but sometimes in pockets. These fragments are generally quite minute, but

in one case they were found nearly half an inch through and apparently from sticks 6 inches in diameter. That these fragments are of charcoal rather than of rotten wood is indicated, although not proved, by their angular character, and the fact that at this same horizon wood is found well preserved. From the presence of the charcoal this has been named the charcoal streak.

The old soil and charcoal streak are found only where the surface of the drift is not eroded. In using the term "old soil" the writer would

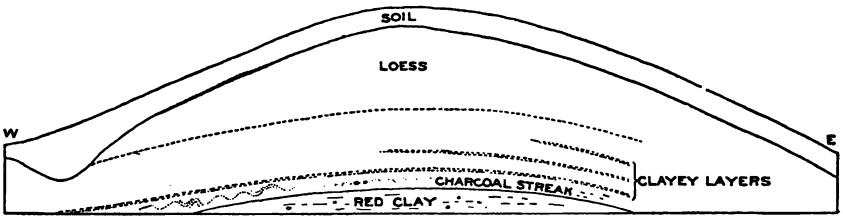


FIG. 20.—Summit cut between Silver and Keg creeks.

not assume that such is its real character. No unmistakable evidence of plants growing in position has been found in it. Although some of the fragments apparently are from roots, examination has not shown them to be in their natural position, while in other localities, as at Malvern, Iowa, the fragments have a slivered and worn appearance, as if they had been transported.

Another question arising at this point is whether this stratum is more closely connected with the loess or with the red clay. Usually the material and structure of the deposit aside from the carbonaceous matter are hardly distinguishable from the loess. Moreover, often the

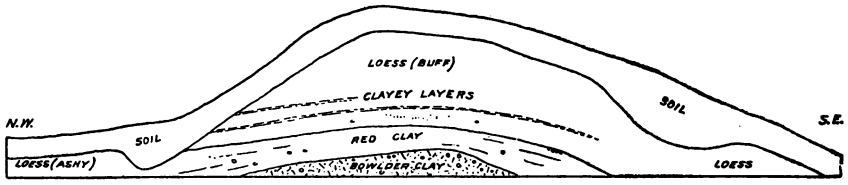


FIG. 21.—Cut on Omaha and St. Louis Railroad west of Walnut Creek, Mills County, Iowa.

junction between it and the red clay is distinctly marked, while on the other hand, although its color ends quite abruptly upward, the body of the deposit seems continuous with the loess. We conclude, therefore, that in most cases, at least in this region, the formation is a deposit of carbonaceous mud. In some localities, especially the more elevated and those toward the western margin of the region, it may prove to be real soil. Figs. 20 and 21 illustrate some of the points mentioned above.

SUMMARY.

The drift in this region is represented by three members—till, red clay, and gravel and sand beds.

The first is confined mainly, if not exclusively, to a belt along the

Big Sioux and Missouri from 30 to 50 miles wide in the northern portion, but rapidly widening below Dakota City, so that in the latitude of Lincoln it reaches from the Big Blue west of the Missouri to at least an equal distance east of that river. The second is found everywhere except where its absence can be referred to erosion. In its pebbleless form it continues westward indefinitely underneath the "old soil." The third is most extensively developed in Knox and Cedar counties, Nebraska, at a high level; but similar deposits are found near the present channels of the Big Sioux and Missouri at much lower levels, especially southward.

As to elevation, the first is mainly confined to medium and lower levels. The second is found at all levels, though more removed by erosion at lower levels. The third occurs at higher and lower levels less frequently than at medium elevations.

The drift, as was long ago recorded by Dr. C. A. White, is less prominently developed near the Missouri.

The base of the drift is found where the blue till is wanting, as in northern Nebraska, and in the lowest levels along the Missouri River in the southern part of the region under consideration; also at other locations throughout this region where older rocks protrude to unusual height. In other circumstances it is not found.

The drift of the region, so far as has been observed, contains no erratics of local origin except within 5 or 6 feet of the original beds.

Striæ are of exceptional occurrence even in localities where they are found. Disturbance of underlying beds has been very rarely observed, and where observed it is of inconsiderable amount.

LOESS.

We proceed to consider the loess, which covers this region as a mantle and, with superabundant folds, spreads farther west and south. In our discussion of its characteristics we shall find it convenient to transcend the bounds of the drift as before laid down.

By the term loess we would designate, in the present case, not simply the kind of deposit, but only the deposits of this kind which were made contemporaneously with its principal development in this region. The silt capping of the high terraces before mentioned and the bulk of some of the more recent terraces are physically indistinguishable from the true loess. The same is true of an older deposit described elsewhere.

Structure and composition of the loess.—The loess has been so often defined that a detailed description is unnecessary. It is composed mainly of fine grains of silica, some of which attain the size of 0.2 of a millimeter, though much the greater number of particles are less than 0.01 of a millimeter. These particles are coated, more or less, with oxide of iron and calcium carbonate. The amount of the former gives it its color, which in the typical form is usually a light buff. With it are

mixed many small grains of clay. The finer ingredients appear to constitute a cement which holds it firmly together, so that it usually stands firm like indurated rock, unless softened by moisture. In the latter case it has a very slow, creeping movement on slope. It is often traversed by vertical fissures, which in some cases may be compared with crevasses in glaciers. In some localities the grains of silica are rather angular, even the largest, but more commonly, so far as observation goes, the larger grains are more or less rounded, sometimes worn smooth, and the smaller grains, though relatively less worn, are apparently as much so as could be expected from their diminutive size and the consequent feebleness of their impact during transportation.

Though remarkably homogeneous, it still shows variations in color, which are often quite conspicuous when seen over extensive exposures. Its usual color is a dull yellow, but it is not infrequently of a light ashy hue, with a bluish cast when permeated with moisture. The distribution of these colors forms one of the most reliable evidences of its stratified character. In the extensive excavations recently carried on near Council Bluffs, Iowa, an obviously darker band could be seen when viewed from a distance, marking a horizontal line for half a mile or more. This was some 75 or 80 feet above the bottom lands of the Missouri. Similar horizontal bands have been traced in cuts of higher elevation and more remote from the Missouri. This obscure stratification has also been found in some cuts to show a curved arrangement corresponding to the surfaces above and below. The ashy appearance in other cases seems to be a result of more recent leaching of the loess by carbonaceous waters. In this way may be explained the frequent occurrence of ashy loess near the ends of cuts.

Extent of the loess.—The boundary of the loess on the west is very indefinitely determined, and must necessarily remain so for several reasons: (1) The obscuring of the limit by the encroachment of the sand from the west, under the influence of the wind; (2) the possible passing of loess into this sandy deposit on the west; (3) the close resemblance of the loess to residuary loams and to lacustrine and fluvial deposits of a different epoch. In general it may be said to extend along the Elkhorn, Platte, and Republican rivers indefinitely westward, while over the areas between it extends not nearly so far. As observed near Friend and Dorchester, Nebraska, the prevalent deposit is not the typical loess, but is much more clayey, and the yellowish tint is replaced by a reddish, so that it resembles a deposit found elsewhere beneath the loess. Whether this deposit is really a clayey equivalent of the loess or whether it is of older formation has not been determined. It has been observed by the writer near Norfolk and thence down the Elkhorn to its mouth; also up the Loup River as far as Scotia, and along the Platte as far as Plum Creek, and deep deposits of it are reported from the vicinity of the North Platte. It abounds, according to Professor Aughey, along the Republican.

The eastern edge of the loess is difficult to determine because the deposit is fragmentary and is deeply covered with soil closely resembling that of weathered drift. The presence of pebbles is usually, though not always, decisive proof of underlying drift, but much of the drift seems covered with a soil in which pebbles are scarce. The eastern boundary of the loess is described by Dr. White in his report upon the geology of Iowa, Vol. I, page 109, viz:

> Commencing at the southeastern corner of Fremont County, follow up the watershed between the East Nishnabotany and West Tarkio rivers to the southern boundary of Cass County, thence to the center of Audubon County, thence to Tiptop (Arcadia) Station on the Chicago and Northwestern Railway, thence by a broad curve westward to the northwest corner of Plymouth County. The last-named point is probably very near the most northerly point to which the deposit reaches, certainly the most northerly one to which it reaches in Iowa.

Further investigation has shown the last statement to be an error. Moreover, the loess continues east of the limit named, becoming of lighter color, coarser texture, and less homogenous, passing in the Des Moines Valley into the second till of McGee.

According to Prof. N. H. Winchell, of the Minnesota survey, it rises to the 1,550-foot contour line in Rock and Nobles counties, Minnesota, or geographically it extends nearly to the southwest quarter of the former county and the southwest township of the latter, with a narrow area along the south boundary of the former county connecting them. In Iowa it is found covering most of the surface of Lyon and Sioux counties. This continues the boundary from the point last named by Dr. White more than 50 miles farther north.

The general statement given in the above quotation is correct, but additions may be made to it as follows: While the eastern edge in Lyon, Sioux, and Cherokee counties is ill defined, in Sac County it follows the watershed, and in Carroll and Guthrie counties the loess terminates in a thick, abrupt edge overlooking the valley of the Middle Raccoon in a way similar to that in which it overlooks the drift region west of the Big Sioux in Lincoln County, South Dakota, from the high bluffs east of the same stream. This feature was first described by Prof. O. St. John in the Iowa reports. It is well shown by figs. 23 and 24 (pp. 101, 102), taken from the same. It will be remembered that a similar relation existed along its northern edge in northern Nebraska and in northwestern Iowa.

In Adams County and adjacent counties in southwestern Iowa the loess extends up the valleys of the principal streams, while the drift occupies the higher country.

Southward the boundary of the loess has not been well determined. It certainly preserves its typical features and undoubted character along the immediate valley of the Missouri to Kansas City and beyond. Several of the Missouri geologists have recognized it in the surface clays covering most of the counties of that State north of the Missouri River.

Fossils in the loess.—Land and fresh-water shells belonging to recent species are found in great abundance in certain localities of the loess. They belong mostly to terrestrial species, but a few are distinctly aquatic. These fossils have not been noticed in northern Nebraska near the moraine, but mostly in southwestern Iowa and central Nebraska. Fragments of unios have been reported from northwestern Iowa, but they seem likely to have been derived from the graves of Indians, by whom they were used as ornaments. They may have been scattered also around camps where they were eaten. In the loess bluffs near the Missouri in southwestern Iowa patches of ash-colored loess are found connected with faint impressions, which seem to be traces of pieces of bark and driftwood, but such can not be positively stated. Some of the horizontal streaks and bands of ashy loess may mark the former deposition of vegetable matter which by its decay in its porous surroundings has reduced the sesquioxide of iron, which gives the yellow tinge to the loess, to a carbonate which has been removed. In several localities detached bones and teeth have been found 20 feet or more below the surface; but as a whole the loess is a remarkably barren deposit.

In some localities certain horizons in the loess are very rich in fossil shells over considerable areas. At Missouri Valley, Iowa, 3 or 4 feet above the horizontal junction of the loess with the red clay, numerous specimens of *Helix alternata* and *Succinea obliqua* are found with more common smaller species. The exposures exhibiting these are along the bluffs facing the valley west.

At Council Bluffs a horizon of similar shells occurs 4 or 5 feet above a dark layer resembling what has been called elsewhere the "old soil," but in this case it is found far above the base of the loess, at least 40 feet, and how much more can not be stated, as the drift is not exposed at that point.[1]

Concretions in the loess.—These have been well described by Professor Call,[2] as well as by others earlier. A few notes concerning their distribution may be added. They abound at certain levels, within 100 feet above the present bottom lands of the Missouri, in great profusion. They are occasionally found in horizontal bands, suggesting their formation along an ancient water level. Sometimes, however, especially in greater altitudes, they appear in curved lines approximately parallel with the present surface. Such a case suggests their correspondence with the upper surface of a portion of the loess which at one time was water-soaked. Their frequent association with holes formed by roots suggests further the idea that they have been formed by the reduction of the dissolved bicarbonate of lime to the carbonate by evaporation.

[1] For further and more complete statements regarding the loess fossils of this region, see S. Aughey, Hayden's annual report for 1874, pp. 266–269; R. E. Call, Am. Nat., 1882, p. 380; F. B. Meek, Geol. of Missouri, vol. 2, p. 215 (this does not exclude fossils from the alluvium); J. E. Todd, Proc. Am. Assoc. Adv. Sci., vol. 27, p. 235. B. Shimek, Proc. Iowa Acad. Sci., vol. 5, p. 32.

[2] A paper published in The American Naturalist, May, 1882.

Such an explanation will not, however, explain the curiously cracked interior of the concretions. Although their calcareous character is so prominent, a little examination shows that they are largely composed of such siliceous grains as constitute the bulk of the loess. That they were not first masses of calcareous mud, perfected by concretionary action, seems evident from their position, which is usually with the longer axis vertical. Their cracked interior, rather than the result of its shrinking, as has been frequently suggested, is more probably produced by the expansion of the exterior by the building in of fresh particles from time to time between those already deposited. The age of these concretions may not be very great, for they are frequently observed in loess which has been recently rearranged.

Besides the calcareous concretions which have been considered thus far there are frequently found concretions of iron oxide. These are formed universally around decayed roots or root marks, and are sometimes elongated so as to resemble lead pencils in size and shape. Usually in their axis is an opening formerly occupied by a root.

Origin of the loess.—In comparing the loess with the extensive Cretaceous clays exposed along the Upper Missouri, and evidently forming much of the floor upon which the drift sheet of Dakota rests, one is struck with the abundance of silica in the former and the almost entire absence of it in the latter. Hence the idea that the loess is mainly the product of the grinding of the glaciers, at least so far as the Dakota lobe is concerned, seems to be erroneous. If, however, we turn to the Tertiary deposits of the plains west, we discover vast beds of very similar loams, in both the Loup Fork and the Laramie formations. There is underneath the prevailing greenish quartzite, which here and there caps the table-lands along the Ponca Reach, a deposit 10 to 20 feet thick scarcely distinguishable from the loess. Trace of apparently the same formation is mentioned by Prof. N. H. Winchell in his report on the Ludlow expedition, as found along the Cannonball.[1] It seems probable, therefore, that much of the loess material was derived from the western tributaries of the Missouri and not exclusively from the beds stirred up by the Dakota glaciers, and yet there is a probability that these sandy beds may have formerly extended into the James Valley, and so may have contributed to the loess through the instrumentality of the ice sheet. The calcareous and alkaline ingredients of the loess, on the other hand, were probably derived from the alkaline clays and chalk beds in southern South Dakota. These have given it some of its cementing constituents, which are the cause of some of its most peculiar physical properties.

Thickness of the loess.—The regularity in both the upper and the lower surfaces of the loess before mentioned is likely to mislead one in estimating its thickness. Several writers have apparently taken the distance from the summit of a hill to the highest exposure of the drift

[1] See report of Captain Ludlow's reconnaissance of the Black Hills, 1874, p. 23.

appears on the west side of the creek and is spread out in shallow beds in an irregular manner upon its outer slope. Where the moraine consists of a few small hills about 9 miles east of Spirit Mound and just west of Brule Creek the inner range, rising 75 feet above the plain west, is very bowldery. The second range, about half a mile east, which rises 80 feet higher, has every appearance of being covered all over its summit with loess. No erratics were found, and badger holes showed only loess with calcareous concretions.

Southwest of Beresford, in the shallow cuts along the railroad, another opportunity was afforded to study this point. In the first cuts nothing

FIG. 24.—Section near junction of Middle Raccoon River and Willow Creek, Iowa.

but pebbly clay or disintegrated yellow till was seen below the soil, but about 30 feet below and about a mile distant from that town, which is upon the summit of the moraine, the loess begins to appear. In the first case it was in a portion of the cut covered with several feet of pebbly loam, which may be explained as a wash from the hillside west. A little farther east and 40 feet lower it showed its typical character, and began to cover the hills gradually toward the east. In Lyon County,

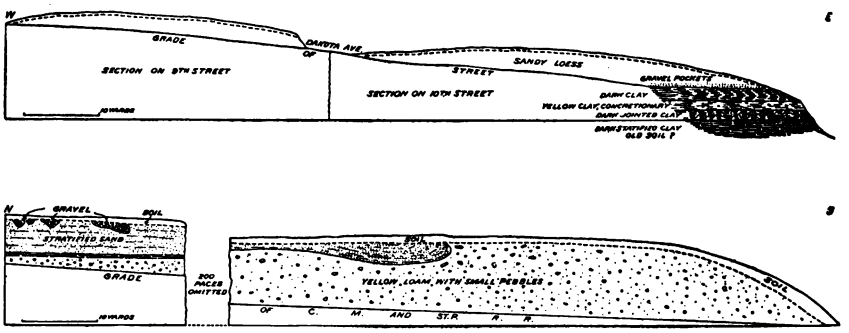
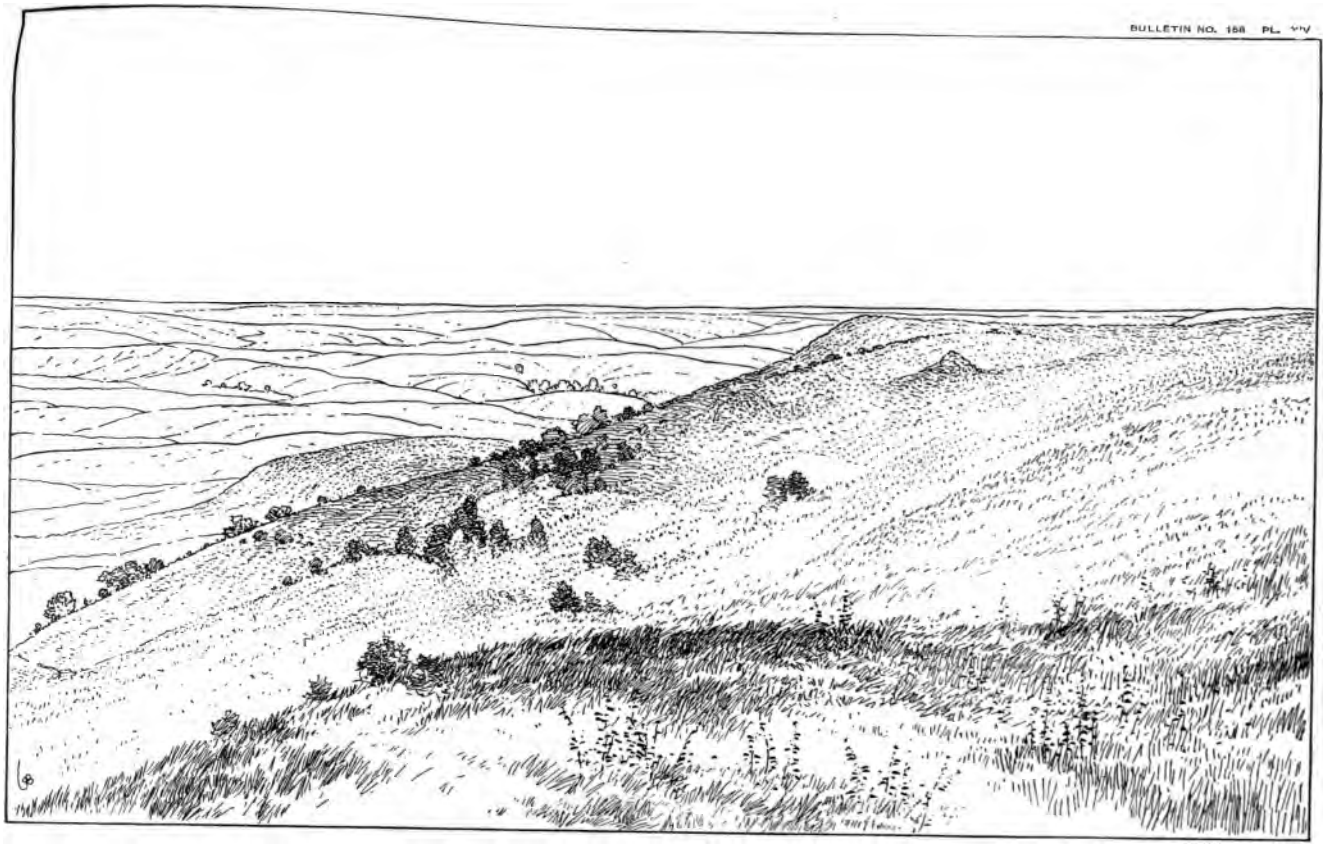


FIG. 25.—Sections at Sioux Falls, South Dakota.

Iowa, and Rock County, Minnesota, the drainage, as in northern Nebraska, is generally southward from the inner edge of the loess.

About Sioux Falls the loess occupies the hills in the bend of the Big Sioux. Underneath it lies darker clay, perhaps an old soil, below which are beds of pebble clay. When the loess was deposited the falls could not have been in existence. Some of the characteristic features may be seen from the sections shown in figs. 25 and 26. It is found rising



EASTWARD VIEW FROM NORTH EDGE OF THE LOESS SOUTH OF HERRICK, NEBRASKA.

about 75 feet above the Milwaukee station, or to an *altitude of 1,455 feet* above the sea, and is here again close to the exterior of the moraine This, though arrived at quite independently, corresponds well with its

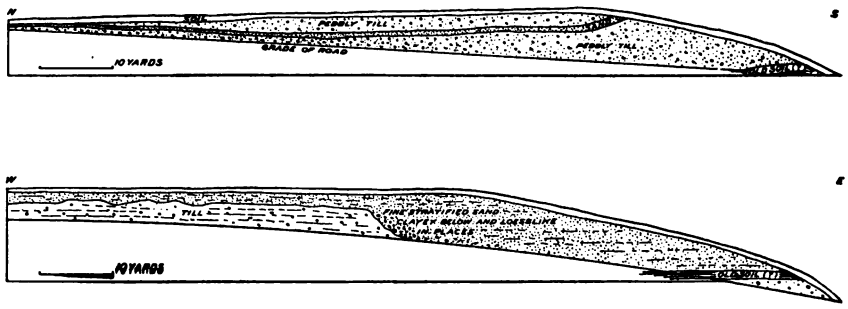


FIG. 26.—Sections at Sioux Falls, South Dakota.

altitude east of Beresford and at Warren, Iowa, and with the reports of Prof. N. H. Winchell respecting southeastern Minnesota.

COTEAU DES PRAIRIES REGION.

This region in some sense may be called the counterpart of the Red Lake region. It lies nearly in the same latitude, occupies an external angle of the moraine, and its features suggest lacustrine origin.

Boundaries of the Coteau region.—The line of separation between this and the moraine on the west may be located as follows: From the vicinity of Brookings southwest to Madison, thence southeast to Hartford and the mouth of Skunk Creek, thence northeast along the north bend of the Big Sioux and east to Luverne, thence north to Pipestone, thence north and northwest to the vicinity of Brookings. The northwest boundary corresponds well with the northeast course of Battle Creek, the southwest boundary, in general, with the west side of Skunk Creek Valley, the eastern boundary with more prominent outcrops of the Sioux quartzite.

Surface of the Coteau region.—The surface may be described in general as a plain lying between the east side of the Dakota loop and the west side of the Minnesota loop of the outer moraine. This plain slopes toward the south at the rate of 4 or 5 feet per mile. Where crossed by the railroad between Pipestone and Madison its altitude is very uniformly 1,690 feet above the sea. Where it is crossed in its southern portion the altitude is from 1,460 feet north of Valley Springs on its eastern side to 1,575 feet on its western side near Hartford. The general elevation there can not be so accurately given because the plain has been very much eroded. As will be seen from the map, its southern portion is much traversed by streams, which have by their numerous branches quite destroyed the surface of the original plain, especially toward the southeast. On the other hand, the northern portion of the

plain. It should be noticed also that the Madison Lake channel is mainly external to the moraine, while the other passes through the moraine. We may notice also a correspondence between these two streams and the two principal branches of Smith Creek, in the Red Lake region.

The lower course of Skunk Creek lies in a broad, flat-bottomed valley with abrupt sides, and with its western bank, where it has been examined, nearly 100 feet higher than its eastern. Furthermore, the western edge of its valley is covered with bowldery knolls, suggesting a morainic origin; but more probably they are of the same formation as the bowldery osar-like ridges to be described in a future section.

Split Rock rises in Pipestone County, Minnesota, and flows south and southwest to the Big Sioux below the great bend. The most important tributary, which is in some sense the principal stream, is Pipestone Creek, which, rising near the same point, joins the Split Rock on the Minnesota line 6 miles south of the northeast corner of Minnehaha County. Its valley has been so affected by the red quartzite that it has been frequently wrongly mapped. In Palisade Township it passes through a narrow gorge about 4 miles in length. This is walled below on either side with perpendicular walls of quartzite. These rise about 60 feet above the water, and the gorge in its narrowest place is about the same in breadth. The confining of the stream by this rock has prevented the widening of its valley, as is frequent in other streams of the region. It is not probable that this gorge is mainly the work of the Split Rock, because its rocky sides are not continuous. They recede at many points some distance from the stream, and become buried by the drift. In such localities they are, nevertheless, cut into chimneys and cliffs, as though they were formed by some agency long before the later deposit, possibly by ages of weathering, perhaps by the action of the sea itself. Just below Palisade another tributary comes in from the north which has a wider valley, and on this account has had the credit of being the main stream. The exposure at Palisade has been well described by Mr. Warren Upham in the thirteenth annual report of the Minnesota survey. Considerable valuable information has also been given concerning this locality in the Fifth Annual Report of the United States Geological Survey, page 201. The plate facing that page, however, gives an exaggerated idea of the breadth of the gorge. As the treatment of the older rocks is foreign to this paper, the reader is respectfully referred to those works for further information.

About the center of Brandon Township is an exposure of diorite for some rods along the west bank of the Split Rock.[1] It is much decomposed and is presumably an intrusive formation. In sec. 23 the red quartzite is again exposed near the surface of the stream, with several feet of chalkstone (Niobrara) directly above it. The junction between

[1] This is the rock which, since my examination of it, has been reported by Prof. W. H. Hobbs to be olivine-diabase.

the two, however, is not exposed. The numerous striæ found upon the rocks in the localities mentioned, and others farther east, will be considered in detail in another section.

The Big Sioux enters the region under consideration near Brookings, in a valley from three-fourths to 1½ miles in width. Above the mouth of Battle Creek its valley is quite wide and about 140 feet below the high plain west, which is a narrow extension of that occupying most of the region. From that point to Egan it is bounded by the lower plain, which at the latter point is about 100 feet above the stream. This plain seems not to slope so rapidly as the stream, for at its upper end, near Madary, it is not more than 80 feet above the stream. The valley of the Big Sioux as a whole fails to present the abrupt sides and sharp edges which commonly characterize the other valleys of the region. A reason for this feature may be found in the check to its erosion by its crossing two important ledges of quartzite. One of these is at Dell Rapids. At Sioux Falls the course of the stream has been such that it has failed to excavate so deeply; probably the rock has not been so much exposed to erosion, for its surface is more than 100 feet lower than at Dell Rapids, and the force of the stream has been expended over a much wider surface.

The Dells at Dell Rapids.—There are three gorges at Dell Rapids; one is known as the Wet Dell, one as the Dry Dell, and the third is the present course of the Big Sioux. The course of the stream at the rapids is nearly due west. The Wet Dell leaves the present channel south of the town and takes a south-southwest direction for about 2½ miles, where it strikes the present channel again. It is filled with water through most of its course and might easily be taken for a stream that has been dammed. When the Big Sioux is flooded the water flows through this channel. The Dry Dell leaves the present channel near where it turns south and continues its course westward. It is of less width than the Wet Dell, but is filled with earth to within 12 feet of the top of the rock. Its western end is hidden under the hills forming the west side of the valley. The present channel has excavated the rock to less depth than the Wet Dell. There are two or three pillar-like rocks standing in the center of the stream to a height equal to the ledge at the side. One of these has been utilized as a pier for the railroad bridge. Below the Dells the hills along the Big Sioux Valley are rarely over 80 feet above the stream. The surface of the quartzite above Dell Rapids is compact and even-topped, but shows few striæ. East of the Wet Dell a few were found bearing S. 25° E. to S. 40° E. The red quartzite appears again about 4 miles west of Dell Rapids, where it is 100 feet higher than at Dell Rapids.

Below Dell Rapids the Big Sioux continues the general features of the valley above and keeps a straight southerly course to the southern point of the Great Bend at Sioux Falls, where it turns sharply, first northeast, and then northwest and north, falling over the ledge of

quartzite (a height of about 80 feet), and then continuing in a northeasterly course to the vicinity of Brandon, where it turns sharply to the south again, which course it keeps for some distance. The distance from its sharp south bend to its sharp north bend is 10 miles, directly northeast. The fall of the river through this region may be learned from the following elevations, derived from railroad levels. In each case the level of the water is given.

Elevations along the Big Sioux, showing grade of river.

	Feet.
East of Volga	1,596
Near Egan	1,510
At Dell Rapids	1,476
West of Sioux Falls	1,403
At the Chicago, St. Paul, Minneapolis and Omaha Railway east of Sioux Falls.	1,381
At the Chicago, Milwaukee and St. Paul Railway	1,369
West of Brandon	1,281
East of Canton	1,217
Riverside near mouth	1,079

Great Bend of the Big Sioux.—The bend of the Big Sioux at Sioux Falls is remarkable in two or three particulars. In its present course it flows south to the north edge of the quartzite ledge, it would seem for the express purpose of forming a durable series of rapids for water power. The Sioux quartzite is exposed west of the city near the level of the stream, and east of the town over nearly the whole surface of the falls, which are more than half a mile in length. The neck separating the bottom land north of the town from the gorge northeast is considerably lower than the hills in the bend farther south, and is less than 20 feet above the bottom land on the northwest. Its form and structure indicate that at one time the stream flowed across the neck. Why then did it not continue to do so and cut down through the till which probably forms the most of it? If it had done so it is probable that there would have been no falls; at least not until the river had cut back to the rock at Dell Rapids. (It may be that the quartzite occurs south of that place, but such is not known to be the fact.) The answer is believed to be probably the following: We have seen that there was much drainage from the ice sheet northward south of Sioux Falls, and when the ice occupied the outer moraine Skunk Creek was the channel by which all the Glacial streams from the vicinity of Volga to Sioux Falls found escape. Even supposing that the Big Sioux at that time took the shorter course, it is easy to see that the western side of the channel would be cut down most rapidly, and in this way the main channel would be drawn westward and southward until forced northward by the contact with the moraine and strong currents pouring over the lower portion of the moraine at that point. It may be stated here that while we have given, as we suppose, the immediate cause of the bend, the primary cause is to be found in the advance of the ice across the pre-Glacial course of the Big Sioux. No developments have been made

to corroborate the supposition, but it seems not improbable that the pre-Glacial course of the Big Sioux may have been southward into the Vermilion, and that in the advance of the ice toward the east there may have been a damming of the streams coming from the north, and the formation of a glacial lake over this region somewhat as was conceived to have been formed in the Red Lake region; with this difference, however, that while in the latter case it was of temporary duration, in this case the lacustrine epoch continued until the basin had become completely filled with drift material.

Bowldery knolls in the Coteau region.—In speaking of the moraine, reference has already been made to systems of osar-like ridges found on its outer slope. These extend out upon the extramorainic plain, and we will here give the more detailed description which has been promised. The system in this region which has been most closely observed is the one 5 to 6 miles northeast of Montrose. Its more prominent features are illustrated in Pls. IX and X.

The bowldery knolls are from 15 to 35 feet in height, and are arranged for the most part in a rude linear system lying in the bottom of a shallow valley which leads from a col or sag in the moraine eastward and southeastward to a branch of Skunk Creek. The head of the system, which begins quite gradually, lies along the north side of a channel-like lake half a mile long and perhaps a quarter as broad. This lake cuts the crest of the moraine transversely. As in the case of similar knolls near Crow Lake, the surrounding slopes are comparatively free from bowlders. Like that system, also, this one receives a branch which lies in a valley joining it from the northwest. The recency of the topography is attested by the occurrence of basins beside the knolls, which are yet undrained. The lake is about 40 feet below the highest adjacent point on the crest of the moraine, about 240 feet above the East Vermilion at Montrose, and 170 feet above the plain farther west. This system, like the systems in the Red Lake region already referred to, lies above the level of the loess.

The interior of the knolls was nowhere exposed, hence we can say nothing of their structure from direct examination; but from their general appearance as compared with some which were excavated northwest of Waterbury, South Dakota, we should expect to find them largely composed of stratified material.

Along the western edge of Skunk Creek Valley, also, there are bowldery knolls which rise to the height of 20 or 25 feet above the ponds just west of them. Though these have not been connected with gaps in the moraine, their proximity to an important stream and their separation from the morainic hills farther west by a plain 3 or 4 miles in width, as well as their lower elevation, may be taken as evidence that they belong to the same class of deposits as those already mentioned.

Along the Split Rock are found systems of knolls which appear to

be of a rather novel character. They are of rounded form and are found in clusters rather than in ranges. The most important cluster that has been observed is about 6 miles southwest of Pipestone. They rise to the height of from 25 to 40 feet above the general level and nearly 200 feet above the Split Rock southeast. They are arranged around the head of a valley leading into that stream. The slope of the southeast side of the valley, rising 120 feet, is wholly occupied with the red quartzite. There are about fifteen knolls in this cluster, and it occupies most of the surface of two sections. A few others are found along the east side of the Split Rock below the junction with Pipestone Creek, but they are found only in clusters of two or three. From their form and altitude they stand out conspicuously, although they do not attain the height of the first cluster, not rising generally more than 150 feet above the stream. These, which are near Garretson, South Dakota, have been referred to on a previous page. All of these knolls present the same features. Their summits are covered with pebbles and a few small bowlders. Two exposures were examined which had been made by the opening of the summits of these hills for gravel and sand. Their interior structure, where examined, was found to consist of irregular layers of pebbly clay and stratified gravel and sand to a depth of 5 or 6 feet. Below that for 5 or 6 feet farther pure sand was found. Whether the sand comprises the bulk of the hill has not been learned. Their form and position suggest the idea that these hills were primarily dunes which have been thinly veneered with drift and somewhat shaped by aqueous and glacio-natant action. This is not easily reconcilable with the supposition that this locality has been swept very lately, if at all, by an ice sheet.

Hummocks in the Coteau region.—At various points the red quartzite ledges present the peculiar phenomena which may most aptly be described by this term. The upper layer of the rock becomes bulged, and is heaved up in a domed or conical form to the height of 5 or 6 feet. These have been described by Prof. N. H. Winchell in his report on Rock County, Minnesota. The surface of the hummock is covered by these blocks in their natural order, but with the joints between them broadening more and more toward the center of the hummock. That they are of recent origin is indicated by the occurrence of striæ around them, as if they were not in existence when the striation was in progress. Professor Winchell's suggestion that they may have been caused by ice—i. e., alternate freezing and thawing with the change of seasons, aided by the force of vegetation and a little soil gradually getting into the openings—seems quite plausible. They are apt to occur at equidistant intervals.

Striæ in the Coteau region.—The red quartzite, which is frequently exposed in this region, abounds in striæ. They present several novel features. The striæ are distinctly shown, rarely more than 2 feet in length and not often more than one-eighth inch in depth. They are

commonly quite minute. They are frequently attended with crescentic cracks, whose ends incline toward the direction of movement. These are arranged parallel with one another at approximately equal distances. Systems of these are found with breadths of from one-half inch to 18 inches, and may sometimes be 3 feet in length. The larger ones reveal more of a parabolic than circular form. In the larger systems the longer cracks are intercalated with the shorter ones, suggesting the coexistence of two systems of vibration. The general appearance of such a system is fairly represented in fig. 27 (1), which was carefully drawn from nature. Not infrequently the striæ with which these crescents are connected have been worn away, and the crescentic cracks are the only record remaining of the original marking. The depth to which the cracks extend varies from the merest trifle to at least an inch, and it is not improbable that further examination may increase this figure.

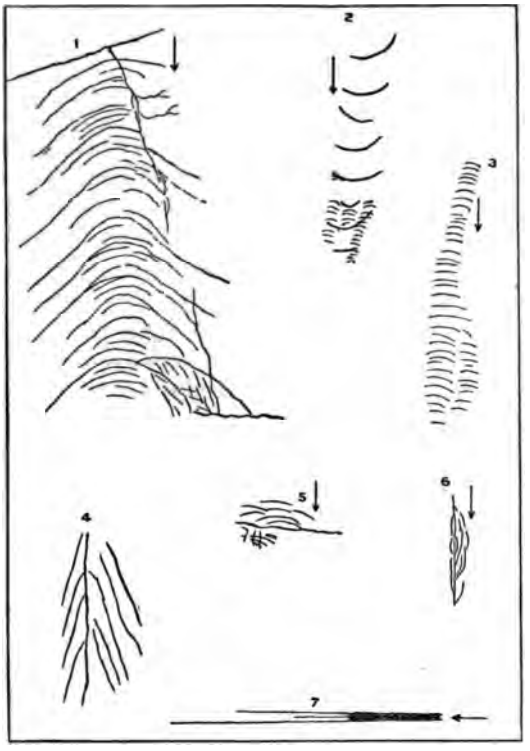


FIG. 27.—Various markings on Sioux quartzite.

The inclination of these cracks to the surface, near the axis of the system, is forward, but gradually turns backward as the distance from the axis increases, until it may incline quite strongly backward.

Besides these cracks, which are clearly referable to ice action, there are others resembling them somewhat, in which the crescentic marking turns in the opposite direction. These are also apt to show an equidistant arrangement, but are never as near together nor as regular in their shape and position as those already described. They may be ascribed, with considerable confidence, to the ripple marks preserved in the stratification of the rocks. Fig. 27 (2) shows a case where both these kinds of markings occur.

A careful study of the striæ of this region shows more variation in direction than has been commonly ascribed to glacial action. This will appear from the table of striæ given below. Not infrequently three or

four systems of striæ, of widely varying direction, occur upon the smooth surface of the rock with equal distinctness. Some of the novelties which have been observed are shown in fig. 27. Curved striæ not infrequently appear.

Striæ found in the Coteau des Prairies region.

[Corrections are made for magnetic variation.]

Locality.	Direction.
Pipestone, Minnesota:	
Near the Three Maidens	S. 30°–26°–28°–40° W. S. 14° E.
Near Pipestone Falls	S. 1°–19°–24°–27°–28°–37° W. S. 0°–2°–3° E.
Pipestone City	S. 22°–23°–25°–26°–32°–37°–38° W. S. 34°–42°–38°–45° E.
Three miles southwest of Pipestone	S. 3°–7°–13° E.
About 8 miles SSW. of Pipestone	S. 22° W.
Four miles north of Palisade	S. 14°–18° E.
Palisade:	
At the southeast edge of exposure.	S. 33°–38° E.
One mile east	S. 23° E.
One and one-half miles south of Palisade.	S. 13°–18°–28°–48°–53°–58°–63° E.
Two miles north of Valley Springs	S. 8°–53°–62°–63° E.
Northwest corner of Iowa	S. 8°–9°–13°–16°–18°–19°–23°–30°–38°–53° E.
Opposite mouth of Split Rock:	
Inside of the moraine	S. 13° E.
One mile outside of the moraine	S. 13° E.
Sioux Falls:	
Near Milwaukee station	S. 13° curving to 8° E.
East of Cascade mills (recent)	N. 28°–45° W.
Southeast of Queen Bee mill	S. 43°–53° E.
East of C., St. P., M. & O. station	E. [mag.] = S. 88° E.
Dell Rapids, east of Wet Dell	S. 13°–23°–28° E.
Four miles west of Dell Rapids	S. 2° W. S. 3°–13°–18° E.

CHAPTER IV.

THE DRIFT REGION INSIDE OF THE OUTER MORAINE.

This is naturally divided into three principal parts: The second moraine, the region between the moraines, the portion inside of the second moraine.

SECOND OR GARY MORAINE.

Several circumstances combine to make the second moraine less prominent in height, in breadth, and in complexity:

(1) It was formed upon a nearly level plain left by the great ice sheet. There were therefore no very prominent features to distort or elevate the moraine, as was the case with the outer moraine.

(2) Another circumstance, which was also a result of its formation upon a plain, was its predominating tangential drainage. As the ice sheet retreated from the principal moraine, its edge in general withdrew to lower ground. Hence while occupying the second moraine the waters tended to flow along its edge to the two principal streams, the James and the Vermilion. This tangential drainage tended to erode the moraine in some cases and to bury it in others.

(3) The ice sheet had probably diminished considerably in thickness, at least toward its lower margin; therefore its pushing power and probably its velocity had decreased. Both of these would diminish the amount of the material crowded into the moraine.

(4) It is not unlikely that the period of formation of the second moraine was much shorter than that of the first.

Northeast of Turtle Point 6 or 8 miles, and occupying the narrow space between Firesteel and Sand creeks, is a range of stony hills presenting the usual features of a moraine. It rises frequently to the height of 100 feet above the general level, or 130 feet above Sand Creek. Gravel and sand are very abundant, also bowlders of limestone and gray granite. Its extent northwestward has not been determined, but it probably is to be connected with stony knobs southwest of Wessington Station. From the before-mentioned locality northeast of Wessington Springs, the moraine extends in a discontinuous system of irregularly crescentic clusters of sharp knobby hills which are from 20 to 60 feet above the very even plain. Their convexity is toward the west. The inner edge, along which the principal range lies, passes 3½ miles west of Woonsocket, where it rises to an elevation of 75 feet. It is there called the Pony Hills, which are sketched in fig. 28. The

ridge continues 4 or 5 miles farther, then disappears. At Twin Lakes another ridge rises to the height of 30 feet and continues south 2 or 3 miles. Light bowldery ridges just east of the Firesteel in Jerauld County should doubtless be reckoned as portions of the second moraine.

South of Twin Lakes the principal development, which, however, is little more than a broad swell surmounted with a few bowldery knolls, passes 5 or 6 miles west of Letcher in a south-southeasterly direction to the Firesteel northeast of Mount Vernon. South of the Firesteel, in the northern portion of T. 103, R. 61, the surface rises into broken gravelly ridges extending in a southeastern direction. Between them are numerous basins elongated in a northwest-southeast direction, which, from their position and connection, suggest the action of a stream successively shifting from one to another toward the northeast. Possibly the Firesteel formed them after it entered the moraine and followed

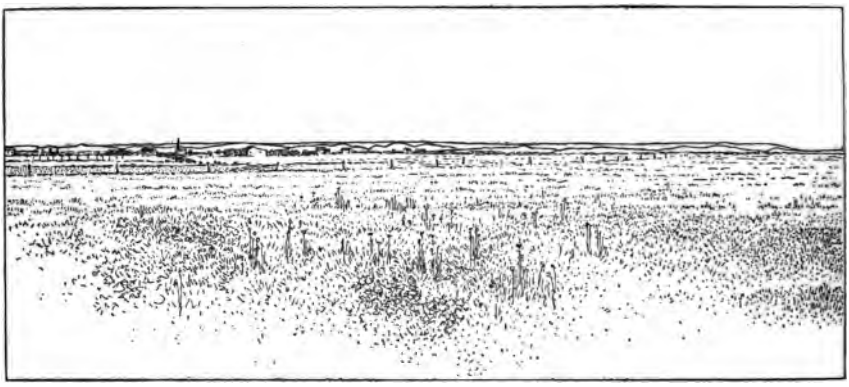


FIG. 28.—Pony Hills, near Woonsocket, South Dakota.

the retreating ice. Three or 4 miles west of Mitchell one of the more prominent valleys near the outside of the moraine connects with Enemy Creek. Four or 5 miles south of Mitchell are two ranges of long narrow hills, about 60 feet in height, lying west-northwest, east-southeast; these are known as Enemy Creek Hills (fig. 29). A view from them shows less conspicuous knolls in the plain to the southwest. These hills form one of the most prominent portions of the moraine. A peculiarity of their position is that they lie on ground lower than that a little northeast of them. One mile east of the junction of the Firesteel and the James is a very conspicuous hill, locally known as Medicine Hill. It rises about 210 feet above the James River, and 90 feet above the general level of the lacustrine plain surrounding it east, north, and west. A range of low hills extends south from it and curves to the southeast. It is evidently the head of an interlobular moraine, which became nearly a glacial island during the latest occupation of this moraine.

West and southeast of Rockport the banks of the James show several stony knobs. These are especially numerous in the northern portion of T. 101, R. 58. It would seem that here, near sec. 2, was the apex of a reentrant angle of the moraine. Extending from near sec. 33, 2 miles east of Rockport, in an east-southeast direction, is a long, shallow, ancient channel, now occupied by a miry slough 2 or 3 miles in length. This is at a level of about 110 feet above the James. About one-half mile east of the river bluffs at Rockport it makes a slight bend from a south-southwest direction, which is about in line with the upper portion of Pierre Creek, to a southeast direction. This part of its course is among very gravelly knobs, rising about 40 feet above it. Among them along its west side is a line of small kettle-hole ponds nearly parallel with it. It continues south to the ravine of a small

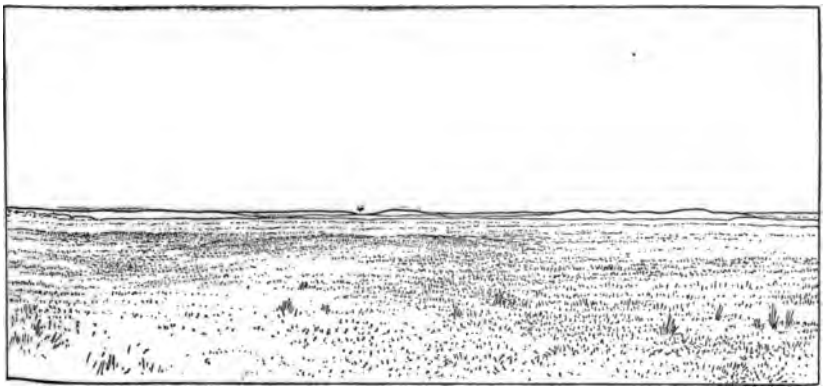


FIG. 29.—Enemy Creek Hills from the northeast. v Enemy Creek.

creek which connects with the James. This channel seems to be a trace of the internal drainage of this angle of the moraine.

In or near sec. 33, T. 101, R. 58, is a cluster of morainic knobs which give an extensive view of the plain to the east, although not apparently up to the level of the land west of the James. Southeast from this point the inner edge of the moraine extends quite directly to Wolf Creek, 2 or 3 miles above its junction with the James. Along considerable of this portion there is found just within the moraine a chain of shallow sloughs and ponds, the moraine itself appearing somewhat like the edge of a terrace rising 40 or 50 feet above these ponds.

In or near sec. 4, T. 99, R. 58, is a cluster of high stony knobs interspersed with deep ponds, some of them covering several acres. These seem to connect in a semicircular curve of low and scattered domes with the high knolls near sec. 33, before mentioned. The moraine has not been definitely traced farther east of James River.

The line described thus far is clearly the inner limit of the moraine, comprising some of the last-formed ridges. It should be remembered that the retreat of the ice sheet had from the nature of the case been

more rapid on the west, hence the ridges are more scattered. Other knolly areas which should be correlated as earlier-formed members of this moraine may be mentioned as follows:

Several miles of knolls along the east side of the Firesteel, about 10 miles west of Woonsocket; another, similarly related to the same stream, 12 miles west of Letcher; a broad strip 2 or 3 miles east of Mount Vernon, extending southeast to Enemy Creek a few miles west of the before-mentioned Enemy Creek Hills; light ridges 2 to 3 miles north of Olivet, trending east of south. Possibly the stony hills east of Olivet and those northeast of Scotland are a modified portion of this moraine, but more likely they are of an osar nature. Then, on the north and east of James Ridge the moraine appears again, first feebly, but rising quite markedly as it turns east across the James in the southern border of T. 95, Rs. 55 and 56, being specially prominent a few miles south of Walshtown. Thence northeast for a few miles it failed to form, probably because at that time the main drainage was in that direction rather than in the line of James River. In the southeastern part of T. 96, R. 55, it gradually rises again.

About 8 miles southeast of Menno is the rather abrupt southern end of a morainic ridge, which extends northward and circles round the northwestern extremity of Turkey Ridge, from which it is separated by a broad, shallow valley. In this valley are the head waters of Clay and Turkey Ridge creeks. Having passed about halfway between Freeman and Childstown the moraine takes a turn more to the east and crosses the West Vermilion halfway between Marion Junction and Parker. Through this portion of its course it may be described as a broad, even-topped swell, rising about 50 feet near Menno, 140 feet near Freeman, and 75 feet near Marion Junction, above the plain to the northwest. Its inner surface slopes rather abruptly. Its outer slope declines very gently. This latter character is best developed southwest of Parker.

One of the most conspicuous points of this moraine is found in sec. 2, T. 99, R. 54, close to the valley of the West Vermilion. It rises about 160 feet above the stream and about 75 feet above the general level. From this point the moraine keeps a course about midway between the East and West Vermilion east of Canistota and northward. While both inner and outer slopes are encroached upon and modified by the drainage into the Vermilions, the summit shows numerous ponds, and at intervals, low stony knobs. The gap through which the West Vermilion passes is quite narrow, with abrupt sides. Five miles west of Montrose the moraine is a simple continuous low swell, a little roughened on its summit. Shallow basins are more numerous on its outer slope and summit. Along its outer foot they form a connected chain in a shallow sag running parallel with the moraine. The summit rises 45 feet above the plain outside and 30 feet above that within.

Similar features characterize it also east and northeast of Howard,

except that rather conspicuous knobs appear here and there, and it approaches more closely to the East Vermilion, its crest being a little west of Winfred. A remarkable line of broad ponds, just east of the summit of the moraine, extends for 10 or 15 miles parallel with the East Vermilion and 2 or 3 miles west of it. This corresponds to the smaller one before noted west of Montrose.

REGION BETWEEN THE SECOND AND PRINCIPAL MORAINES.

GENERAL CHARACTERISTICS.

This region differs from that outside the moraine in several well-marked particulars:

(1). First and most prominently, in the absence of erosive topography, the streams traversing it being usually limited to narrow channels with abrupt sides. There is little or no trace of watersheds. One does not dream of the nearness of a stream till he comes upon the immediate edge of its channel.

(2). The surface everywhere manifests what may be called a sink-and-swell topography. Sometimes the swells or low ridges are much elongated, and have a general trend somewhat like the waves upon the sea. At other times the elongated character is not prominent where there is an indiscriminate mixing of low, rounded domes with shallow, circular basins.

The amplitude of undulation, or the ratio of the difference in altitude between the tops of the hills and the bottoms of the depressions to the distance between hilltops, varies greatly in different portions. In many cases it may be 5 feet to a mile or a mile and a half. Perhaps nowhere in the whole area under consideration is it more than 40 feet to a half mile, and examples of this extreme occur but rarely.

(3). Nothing like buttes is found in this region. While this is true in general, there are inequalities of great extent, probably due to pre-Glacial topography, which will be mentioned as we describe the area more in detail.

WESTERN REGION.

Under this head we would include all of the country lying west of a line running north from the Choteau Creek Hills to the moraine and outside of the latter. This has an oblique, fan-like form, with its narrow or handle portion extending northward, east of Turtle Ridge, and drained by the north branch of the Firesteel.

Where this widens, south of Turtle Ridge, there begins a valley extending southward which is now occupied by the upper portion of the West Firesteel, then with White Lake and the valley of Pratt Creek. This valley lies approximately parallel with the moraine west of it. Although through the most of its course it now contains but little water, it bears evidence of having been at some time occupied by

a stream approaching the James River in size. The watershed between White Lake and the West Firesteel is very low. One would suspect on first sight that the drainage from White Lake was into the Firesteel. Pratt Creek in its lower portion, near Castalia, has eroded a valley over 200 feet in depth, along which are immense beds of gravel and numerous bowlders.

South of the Firesteel the general level gradually rises to an altitude of over 1,500 feet at Plankington and beyond 9 or 10 miles, where the country begins as gradually to slope southward, forming a broad, low swell running east and west, which displays an amplitude of undulation of 5 feet to the half mile. Upon its southern slope lie the deep valleys of Andes and Wet Choteau creeks. About their upper courses, in the vicinity of Grandview, the surface of the country is unusually rough, the amplitude being from 35 to 40 feet to the half mile. The general level of the country gradually rises again as it approaches the moraine southwest, but it does not extend to the moraine, for from the vicinity of Pratt Creek to the Choteau Creek Hills there is a broad shallow valley extending parallel with the moraine, which seems to have been formed by the flow of water toward the principal outlets. This valley near the southwest end of Andes Lake is over 300 feet below the general level of the country south. It is occupied by the tributaries of Pease Creek, by the upper portion of the creek flowing through the Andes Lake Outlet, and by the middle course of Choteau Creek. Elsewhere, also, there are dry channels extending through it, which are probably filled with water in springtime.

Aside from the variations in level which have already been alluded to, there is a more general slope of the whole area toward the east. Yorktown is 230 feet above Mount Vernon, according to railroad levels, which indicates a slope of 10 feet to the mile; yet no one in traversing it would speak of it as other than a very level plain. An indication of a similar slope is derived from a preliminary survey between Chamberlain and Springfield. About 9 miles northwest of Lake Andes the altitude is 1,665 feet, also by railroad levels, while in Lower Choteau Creek Valley, likewise inside the moraine, it is 300 feet lower.

More evidence of this eastward slope and of its probable recent origin is seen near White Lake, and also near Lake Andes, in the apparent change of drainage in recent times. As before mentioned, White Lake and the upper portion of the West Firesteel lie in the same valley. The country east is level and much lower than the country about Plankington. Evidently the drainage of the region was at one time southward into Pratt Creek. Such must have been the case until the ice sheet had receded nearly to the second moraine. At that time, or possibly considerably later, the drainage from the southwest Wessingtons and Turtle Ridge turned eastward, beginning the West Firesteel. This may, it is true, indicate nothing more than the withdrawal of the ice, without change of slope.

At Lake Andes the evidence seems more strongly in favor of the recent tipping of the region. Extending southwest from the southern end of Lake Andes through the gap is a water course less than 10 feet above the water in the lake, which appears as though it had been recently occupied. Southeast from the central portion of the lake extends a long narrow slough, connecting, it is believed, with Wet Choteau Creek. That this is the fact is not certainly determined. Its occupancy by water for several miles in that direction has been observed. The natural suggestion which comes to mind in considering this case is that the plain about Lake Andes has been tipped toward the east, so that its western outlet is now dry, and its waters are seeking drainage toward the southeast by what was, perhaps, formerly a tributary of the lake.

Other reasons for believing in a recent westward elevation of the country will be considered further on. This case is more significant than the last because we can hardly explain the westward flow by the occupation of the eastern outlet by the ice, as in the previous case. We see no reason for supposing that the ice would linger longer in the lower Choteau Valley than near the Andes Lake Outlet, but contrariwise.

Ancient lakes.—In this western region certain areas bear evidence upon the surface of lacustrine origin. These are found, as before stated, in the valley of the West Firesteel, which may be considered as a former extension of White Lake. Another is found southwest of Mitchell, extending from the second moraine southward to the vicinity of Plainview. In both these regions the surface is very level, there being little or no trace of the undulating surface usually found upon the till. Crossing T. 100, R. 62, on the borders of this lacustrine area are two or three slight and disconnected lines of low stony ridges suggestive of morainic action, but possibly due to thrusts of ice against the shore. Along the western border of this latter lacustrine area rise Pony Creek and Twelve-mile Creek, which flow eastward to the James, in valleys resembling those already described.

Ancient channels.—Besides the ancient valley of Pratt Creek and that lying inside the moraine from the Cedar Creek Hills to Choteau Creek, which have been mentioned in our general description of the country, there are several minor ones which are not so closely connected with the general topography.

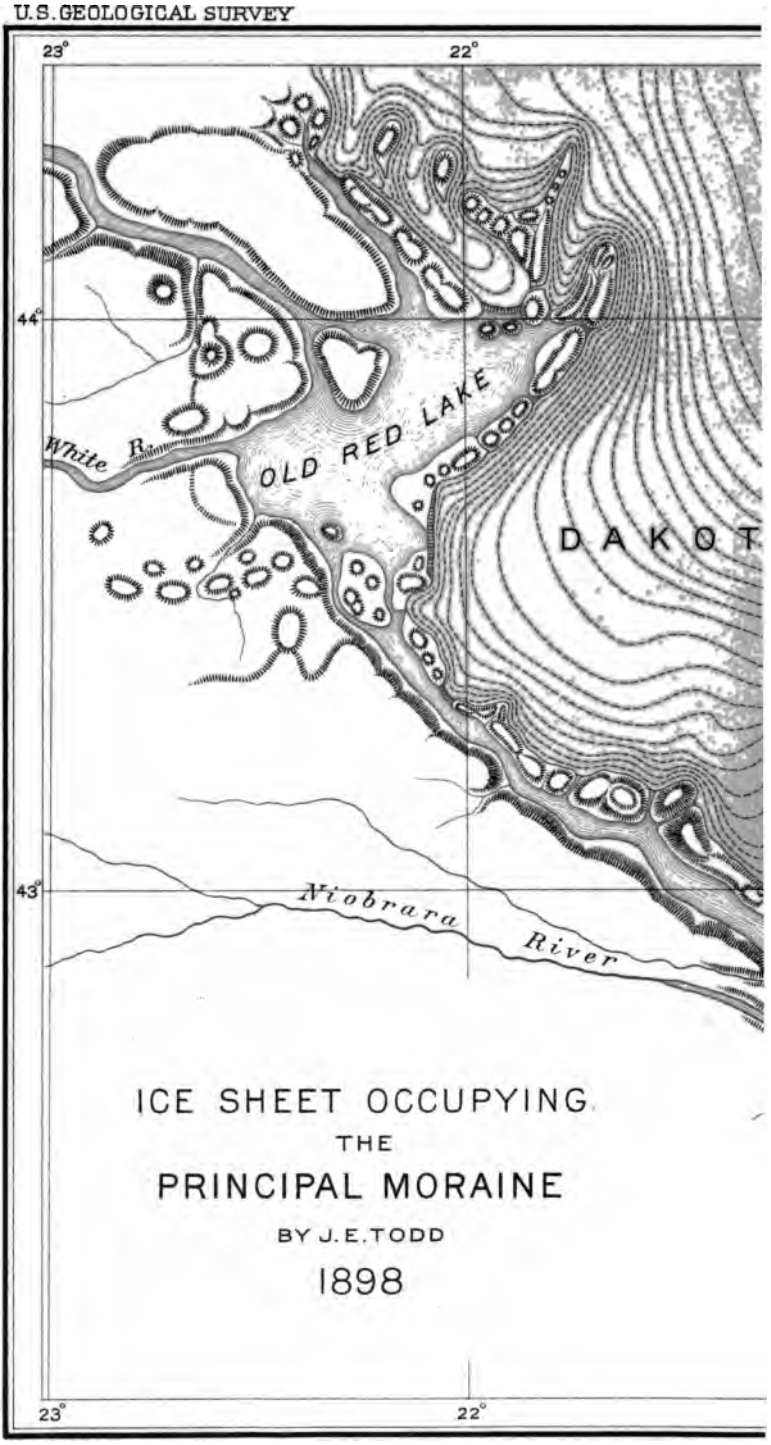
A channel extends in T. 104, R. 63, from the Firesteel to the origin of Enemy Creek. In sec. 34, T. 102, R. 61, a narrow channel with abrupt sides and 40 feet in depth leaves the north branch of Enemy Creek and extends southeast to a branch of Pony Creek. The verification of this last statement was kindly accomplished by Mr. G. W. Bailey, who lives in the vicinity. As this lies in the lacustrine plain before mentioned, it indicates a flow of water around the ice sheet subsequent to the stage in which the lake was formed, a relation which reminds us of what was found in the Red Lake region. Again, a channel extends in T. 98, R. 59,

from Dry Creek to Lone Tree Creek, and the lower course of Dry Creek connects with the mouth of Pony or Twelvemile Creek. By these channels the drainage of the west side of the glacier was effected during the time of the formation of the second moraine, as shown in Pls. XV and XVI.

Wells.—With regard to the structure of the drift formations throughout the area, considerable light has been derived from wells and other excavations. In general, the structure seems to be, as usual, upon glaciated surfaces. First, there is a layer of yellow pebble clay from 10 to 30 feet thick, which passes below insensibly into blue pebble clay, or frequently there is a layer of sand between them.

Along the foot of Turtle Ridge the drift seems unusually thin. The Cretaceous clays are reached within 15 to 20 feet of the surface. Near White Lake the drift is much deeper—more than 50 feet at least. Near White Lake Station several wells of considerable depth were dug, none of them reaching through the drift. The town well was 90 feet deep, most of it being through blue clay. No water had been found when visited. Fragments of wood were found at a depth of nearly 80 feet. One, apparently a root, was over a foot in length and 3 inches in diameter. Generally there is found in that vicinity first 40 feet of yellow clay, then 30 feet of blue clay, then a layer of sand, then blue clay again. Water has not been found except in the yellow clay in basins. At Plankington there is first usually 75 feet of yellow clay, then 55 feet of blue clay, then chalk or shale containing water. Near Grandview, wells, which are usually dug in basins, are about 10 or 12 feet in depth. A well dug in town upon the hilltop, I was reliably informed, was 150 feet deep and had failed to reach water. All below a few feet of yellow clay at the surface was blue clay. Sixty feet of it was dug, the rest bored. No trace of pebbles was found in the last 10 feet. At Mount Vernon a well 108 feet deep, and containing 52 feet of water, was dug through 40 feet of clay, the rest being chalkstone. This chalkstone appears on the general slope of the country 2 or 3 miles west of Mitchell. It also appears in natural exposures near the general level 10 miles southwest of Mitchell, in ravines connected with Enemy Creek; also near the bottom of the valley of the Firesteel northwest and north of Mitchell, and in a ravine southeast of that place. This chalkstone, which before weathering is bluish, and is then sometimes called soapstone, has been struck in wells 8 miles north of Grandview. At Castalia, on a low bottom of Platt Creek, wells 25 feet deep bring to the surface mostly blue pebbly clay. At Plainview wells 44 feet deep were mostly in blue pebbly clay and furnished poor water. At Emsley post-office, a little west of Plainview, a well was observed about 50 feet in depth, which showed little but pebbly clay and very little water. Several miles southwest of Plainview a well 30 feet in depth showed mostly blue pebbly clay, but at the bottom a thin layer of sand and gravel, below which there was apparently shale.

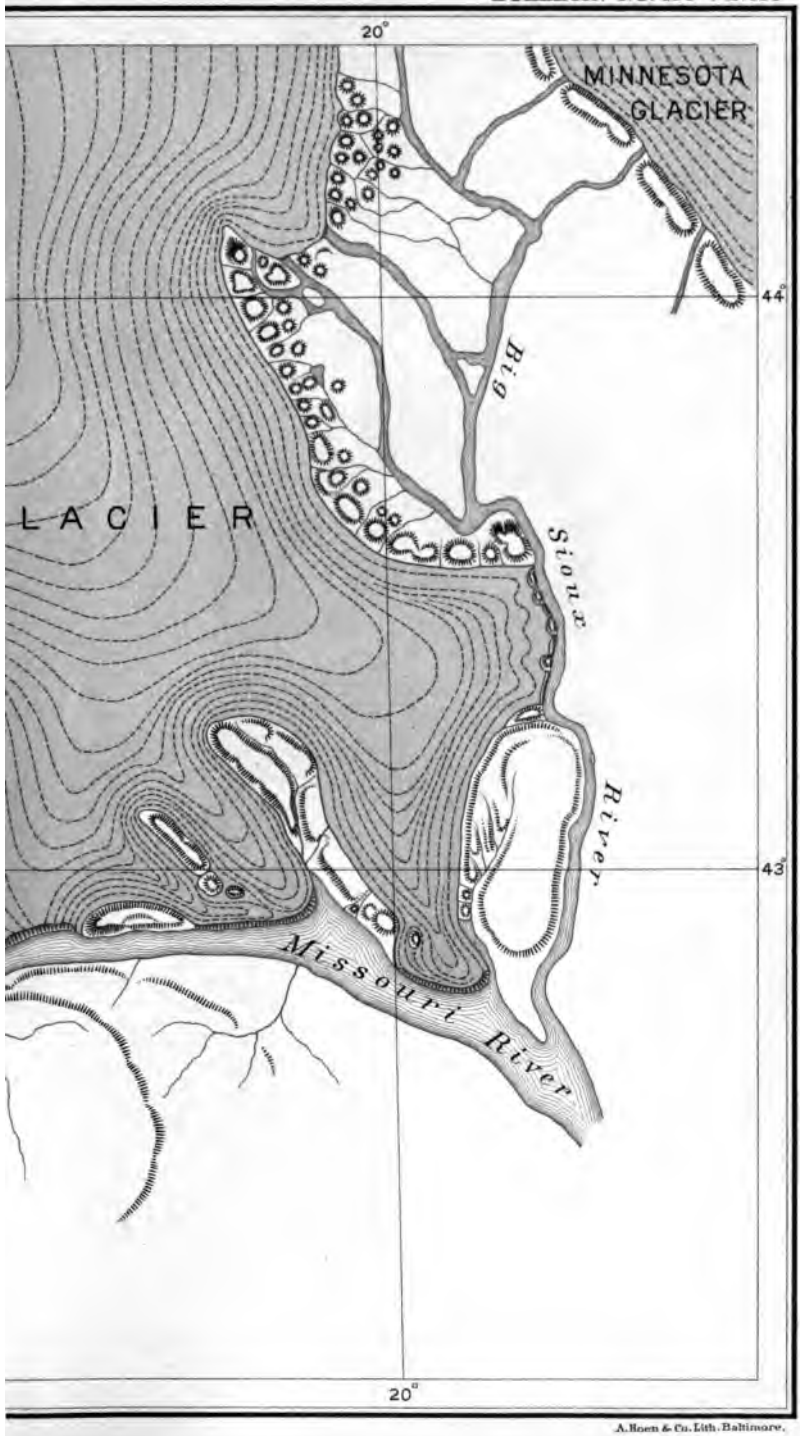
U.S. GEOLOGICAL SURVEY



ICE SHEET OCCUPYING THE PRINCIPAL MORAINE

BY J. E. TODD

1898



A. Hoen & Co. Lith. Baltimore.

In the western portion of the region now under consideration traces of wood have been frequently reported as found in wells. Most of them seem likely to be of the sort already mentioned as having been found in the well at White Lake, which probably is a relic of preglacial or circumglacial forests.

An ancient tamarack swamp.—Near Grandview, in the southeast quarter of sec. 33, T. 100, R. 64, were found traces of more recent occupation of the region by trees. In a well which had been dug on the edge of a basin near a branch of Andes Creek at the depth of 20 feet was found a layer of muck several inches in thickness, in which were pieces of wood with numerous fresh-water shells of nearly a dozen species. But the most remarkable thing was the stem of a hemlock or tamarack about 10 inches in diameter lying across the well, and in the muck were numerous cones evidently of the same species. Overlying this trace of a tamarack swamp was mud of various colors and consistency, evidently washed from the surrounding hillsides. That it should be so deeply buried was chiefly explained by its connection with the channel of Andes Creek. This was conclusive evidence that the region had been occupied more or less by timber since the ice had covered the region, possibly while the second moraine was in process of formation. Similar finds are reported from wells several miles west of that place.[1]

Spotted surface of the country.—One peculiar characteristic of the surface of the country about Plankington and west is the occurrence of patches of clay spread irregularly in the black loam, which is the usual soil upon the drift, and in this portion still forms most of the surface. These clay patches are very irregular in shape and in depth. In wet weather they are very soft and miry, and in dry weather very hard and frequently seamed with mud cracks. They are usually covered with what is commonly called alkali grass (*Triticum repens*), which in the latter part of the summer is dead, while the blue joint and other grasses upon the loam are still green.

In a few shallow cuts near Plankington it was noticed that the clay extended in a horizontal direction and that it and the loam were coarsely interstratified. It is possible that this peculiar character of the country is due to its having been occupied by shallow waters from which clay and loam were precipitated somewhat as clay and sand are deposited upon bars along the Missouri at the present time. Another explanation may be found to meet some cases better, viz, that the clay patches are due to masses of Cretaceous clay carried along bodily by the forces of the glacier and deposited as bowlders which have afterwards been flattened out. Another and perhaps more probable explanation is that alkaline waters continuing in the depressions have dissolved the silica.

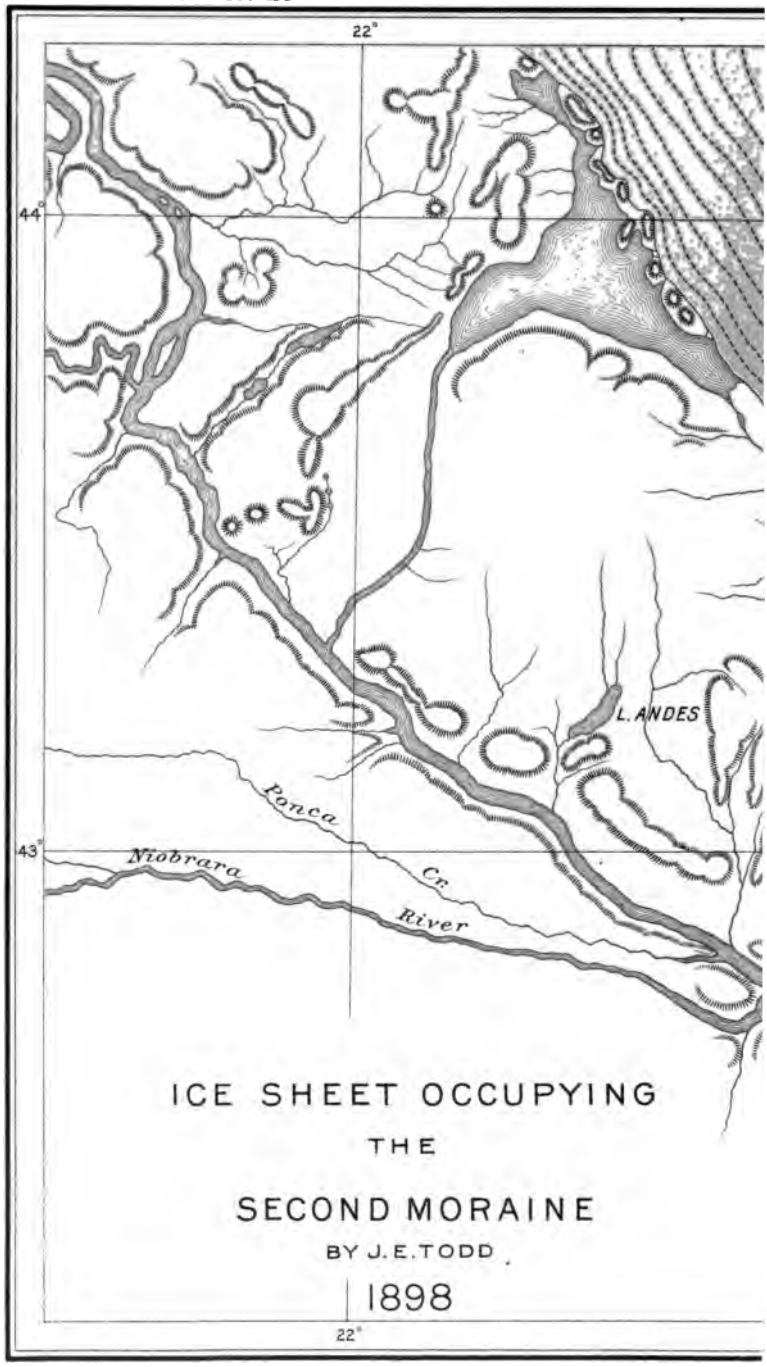
[1] Professor Call determines the fresh-water shells abounding in the muck as follows: *Lymnophysa palustris* Say, *L. deoidiosa* Say, *Gyraulus parvus* Say, *Valvata sincera* Say, *Segmentina armigera* Say.

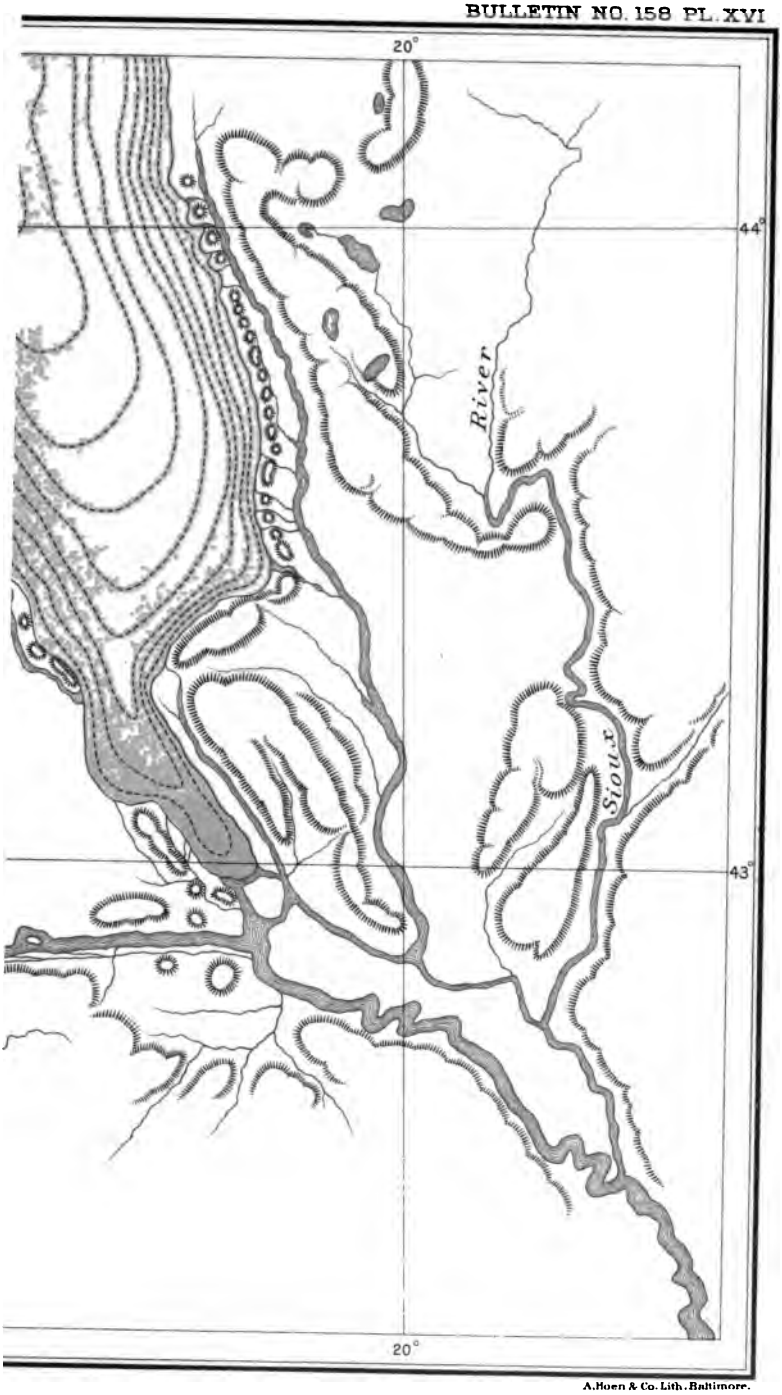
JAMES VALLEY.

This valley occupies the portion between the moraines from the east side of the region already considered to Turkey Ridge, where the two moraines are in contact. The western portion of this region resembles that already described. Perhaps little need be added concerning it. Most of it is nearly level. The exceptions are found near the larger streams and in the vicinity of the principal moraine, particularly near the head of the interlobular portions. We have already noticed the rougher portion, which appears along the eastern rim of the semicircular valley around Choteau Creek Hills. With the rough area near Grandview this may indicate that the ice sheet had a faint tendency to form a moraine between the principal and second moraines. Another somewhat exceptional feature is the occurrence of ponds and lakes in unusual numbers along a line running west from Lesterville for 10 or 12 miles. The principal streams of this region are Emanuel Creek on the west, James River near the center, and Clay Creek on the east. Emanuel Creek, west of Scotland, flows in a wide valley about 50 feet below its eastern rim and at a level higher than the plain a few miles east. Near its mouth it occupies a narrow valley 125 to 150 feet deep. The James River has a valley with abrupt stony sides and from a quarter to half of a mile in width. Its depth at Milltown is about 115 feet; northeast of Scotland, about 150 feet. Clay Creek occupies a broad valley near the moraine, which evidently at one time was the principal outlet from the ice sheet. This valley near the moraine is 50 to 75 feet in depth below the plain northwest. The tributaries of these streams have cut down to the same level near their junctions, and occupy narrow valleys with abrupt sides throughout nearly their whole course. They rise in basins or shallow winding valleys. Through the dry seasons they consist of chains of deep pools, with little or no running water between.

Exposures of older rocks.—Along the James River we discover again many natural exposures of older rocks. The chalkstone of the Niobrara is exposed on the banks of a small stream near Scotland, about 75 feet below the general level. North of Milltown for several miles the Dakota sandstone occupies both banks of the James, rising 40 or 50 feet above the stream. At Rockport is an extensive exposure of Sioux quartzite covering several hundred acres, and just above it, on the east side of the river, there is chalkstone in several localities. Along Enemy Creek both the Dakota sandstone and the red quartzite are exposed, but the latter was too low to be touched by the glacier. The chalkstone shows conspicuously along Clay Creek 120 feet above the stream and about 50 feet above the general level of the plain west. It is also widely exposed along the Firesteel and the channels to the south, including Enemy Creek, as far west as Mount Vernon.

U.S. GEOLOGICAL SURVEY





A. Hoen & Co. Lith., Baltimore.

VERMILION VALLEY.

This region resembles the western region in outline, except that its fan-like portion is more extended toward the southeast. Its narrow part, corresponding to the handle of the fan, is occupied by the valley of the East Vermilion. The general slope of the whole surface is toward the southeast. This is indicated by the present direction of the streams, and there is no evidence of a change of course, as in the western portion of the region between the moraines. There is little trace of lacustrine action except along the Lower Vermilion, and this evidently was greater during the recession of the ice than while the second moraine was forming. Along the east side of Turkey Ridge numerous narrow northwest-southeast valleys indicate the action of running water during the earlier recession of the ice. About Swan Lake, in Turner County, occupying an east-west strip 3 or 4 miles in width, is a rough portion showing many low stony hills and ponds. This continues northeastward past Lenox, and may be correlated with the trace of a minor moraine before noticed. The average altitude of this strip is not greater than the country north and south of it. North of Swan Lake, about Turkey Ridge Creek, the country is unusually flat and clayey, forming the broad shallow valley of Turkey Ridge Creek, which is the principal tributary of the Vermilion.

The East Vermilion and Vermilion form the principal stream of this region. The East Vermilion occupies a deep valley just inside the outer moraine. West of Madison it is about 200 feet below the summit of the outer moraine and about 90 feet below the high swell just west of it, which farther south is the second moraine. In its upper portion it displays a very bowldery terrace along the inside of the principal moraine.

Below the mouth of the West Vermilion the stream passes through a broad basin-like valley, perhaps once a lake, till it approaches Turner or Davis, its immediate valley being only 15 to 25 feet deep. Near Turner its channel deepens to 35 feet, is about 50 feet a little north of Lodi, 60 feet at Bloomingdale, and over 80 feet at its mouth. The broad plain along its lower course is very level and even. It extends with similar characters through the principal moraine and terminates as a terrace of the Missouri River.

There is no distinct watershed between the Vermilion and the Big Sioux. The plain reaches through to the Big Sioux without much variation in level. There is probably a very slight slope to the southeast, but railroad levels scarcely show it. The course of the streams in that direction seems more the result of their following back the ice sheet in its recession.

REGION INSIDE THE SECOND MORAINE.

This portion of our field has a very even surface. From the inside of the second moraine west of the James the surface extends eastward as almost a dead level to the west side of Miner County, where it begins to rise gradually toward the east, and so continues in that direction to the second moraine on the east. This eastern portion presents the usual topography of slight swells and basins, with the further modification of broad shallow valleys running southward. These are occupied by various branches of the Vermilion and the James. Beginning on the east, we have the West Vermilion River, Wolf Creek, and Redstone Creek.

Upon the level portion of this region the streams take a southwest or southeast direction, as the case may be, to the James River. The whole of this region, except it may be a small portion north of Woonsocket, presents the features of an ancient lake bed filled with drift deposits. Its boundary, so far as yet ascertained, lies close along the inside of the second moraine from the vicinity of Woonsocket to Medicine Hill. This line passes a mile or so west of Letcher, through Mitchell, where, however, it is obscured by knolls, thence curving east and northeast around the foot of Medicine Hill. From that point it curves southeast for a few miles, then around again to the northeast and north, and passes about 2 miles east of Diana, and continues north indefinitely. It seems not improbable that this ancient lake extended as far north as Lake Tchanchicaha. This conclusion is strongly sustained by railroad levels. According to the Chicago, Milwaukee and St. Paul survey the altitude of the station at Mitchell, which is a little below the general level, is 710 feet; Letcher, 713 feet; Mellette, which is 100 miles farther north and again on the level of the lake-like plain, 712 feet; Warren, 713 feet; Aberdeen, 715 feet, while in the region now under consideration, Diana, which is near the eastern boundary of the lake, is 727 feet. These altitudes are above Lake Michigan.

The general surface shows a thin covering of silt, but bowlders and pebbles are found a little below the surface. Along the west side of the area there is an old channel, now a marsh called Long Lake, which extends from 2 or 3 miles east of Woonsocket southward to the vicinity of Letcher. Along this marsh and south to Mitchell the surface and subsoil are sandy. Probably this same sandy strip extends northward along Sand Creek, but this has not been ascertained. Around Forestburg, according to report, the sand has collected in well-developed dunes. A portion may be kames. The James River has cut a narrow, sharp-edged valley through this plain. It is 50 feet below the level of the plane near Huron, 60 feet at Forestburg, 75 feet east of Letcher, and 90 feet east of Mitchell.

This lake seems to have been for the most part filled to the level of its surface, but south of Diana (Artesian), and north of Letcher, peculiar

depressions were noticed which may be most readily explained by supposing that the lake at that point was not filled. The surface presents low mounds and broad ridges, irregularly arranged and in some cases isolated, interspersed with shallow marshy basins from 10 to 15 feet below the general level. The mounds between in no case rise above the general level. A ready explanation is that they were at first occupied by ice blocks, while débris from the rapidly melting ice sheet buried them and leveled the general surface. In other words, the region is a "pitted plain," with the "pits" unusually large and confluent.

Flowing wells.—A remarkable feature of the region is the existence of flowing wells in the vicinity of Diana and Forestburg. These are invariably obtained by boring through the till, which is about 100 feet in thickness, to a layer of gravel lying underneath. Sometimes thin layers of sand are struck in the till. The flow is abundant and rises to about 15 feet above the surface at Diana. At all points below that level, as far as has yet been found, flowing wells may be obtained. The most trustworthy and explicit accounts were obtained from Mr. C. J. Croninger, of Diana (now called Artesian). Similar conditions are found near Forestburg, but have not been so carefully examined. At Letcher, also, a flowing well was drilled, but the water was obtained from a much lower stratum, probably the Dakota sandstone. It was at a depth of more than 335 feet. This well was a pioneer of the deep artesian wells that now abound in this region. It was drilled about 1884. A description of the well, furnished by Mr. H. M. Hopkins, who had charge of its boring, is as follows:

Well section at Letcher, South Dakota.

1. Deep soil.
2. Yellow clay.
3. Sand, 1 foot.
4. Blue clay, containing a layer of sand 1 foot thick; this extends to a depth of 100 feet.
5. Gravel and quicksand of several feet.
6. Soapstone, 75 feet, with some slate.
7. Sand rock to the bottom, 335 feet deep.

Cause of Lake Dakota.—The reason why this area was not opened at its southern end so as to prevent the accumulation of a body of water may be traced to the configuration of the bottom when left by the ice sheet, and the failure of the ice to excavate toward the south is readily explained by the extension of the red quartzite across its path. This barrier may be conceived to have so checked the ice as to increase the height of its surface and the erosive action below, just as is the case with a stream in similar circumstances. It would have also increased the velocity of subglacial streams, and in this way may have tended to accumulate masses of gravel. The sandy region along its western side, together with the ancient channel, now a marsh, may be referred to the more recent occupation of that side by the stream, or to the currents flowing through when the lake was filling.

Buried wood.—From several localities reports have come of fragments of wood found in wells. But while suspecting that a deposit of this material might be discovered in the lake, after diligent inquiry in several cases, facts were not found to favor such a conclusion. The fragments were isolated, only a few inches in diameter, and occurred at different depths.

Striæ within the moraine.—The region within the second moraine contains extensive exposures of red quartzite which present in a striking manner the abrading action of the ice. In the following table is presented the more striking observations which have been made. At the westernmost exposure of the red quartzite no striæ have been found, and the occurrence of the Dakota sandstone several feet higher in its close vicinity indicates that it was not subject to the action of the ice.

Striæ found within the second moraine.

[Corrected for magnetic variation.]

Locality.	Direction.
Rockport:	
By the schoolhouse at west side of valley	S. 22°–49°–51°–57° E.
Farther east	N. 89° E. = S. 78° E.
	S. 51°–59°–65° E.
Seven miles north of Alexandria	S. 2°–10°–20°–22° E.
Pier Creek, 5 miles north of Alexandria.	S. 14°–17° E.
Wolf Creek, 6 miles east of last	S. 8°–12°–17°–22°–29°–32°–37°–42°–49°–57° E.
Wolf Creek, southwest of Bridgewater.	S. 12 W. S. 12°–15°–17°–19°–21°–22°–27°–29°–39° E.

Only one locality is found between the moraines, viz, 2 miles east of Parker, where the direction is S. 52° E.

The exposures in this region are rather extensive, the one at Rockport covering more than a square mile. It affords comparatively few striæ, because of its weathered character. By far the finest locality for its display of distinct and vared striæ is southwest of Bridgewater, where many are several feet in length (Pl. XVII). They show curves and crooked lines of remarkable form. One was noted 12 feet long, 2 to 3 inches wide, and about one-fourth inch deep. The crescentic cracks are also finely exhibited; a system 18 inches wide and 3 feet

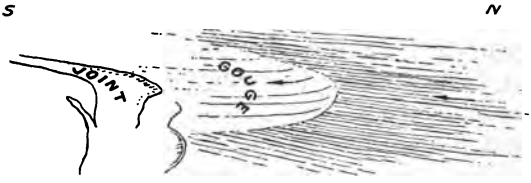
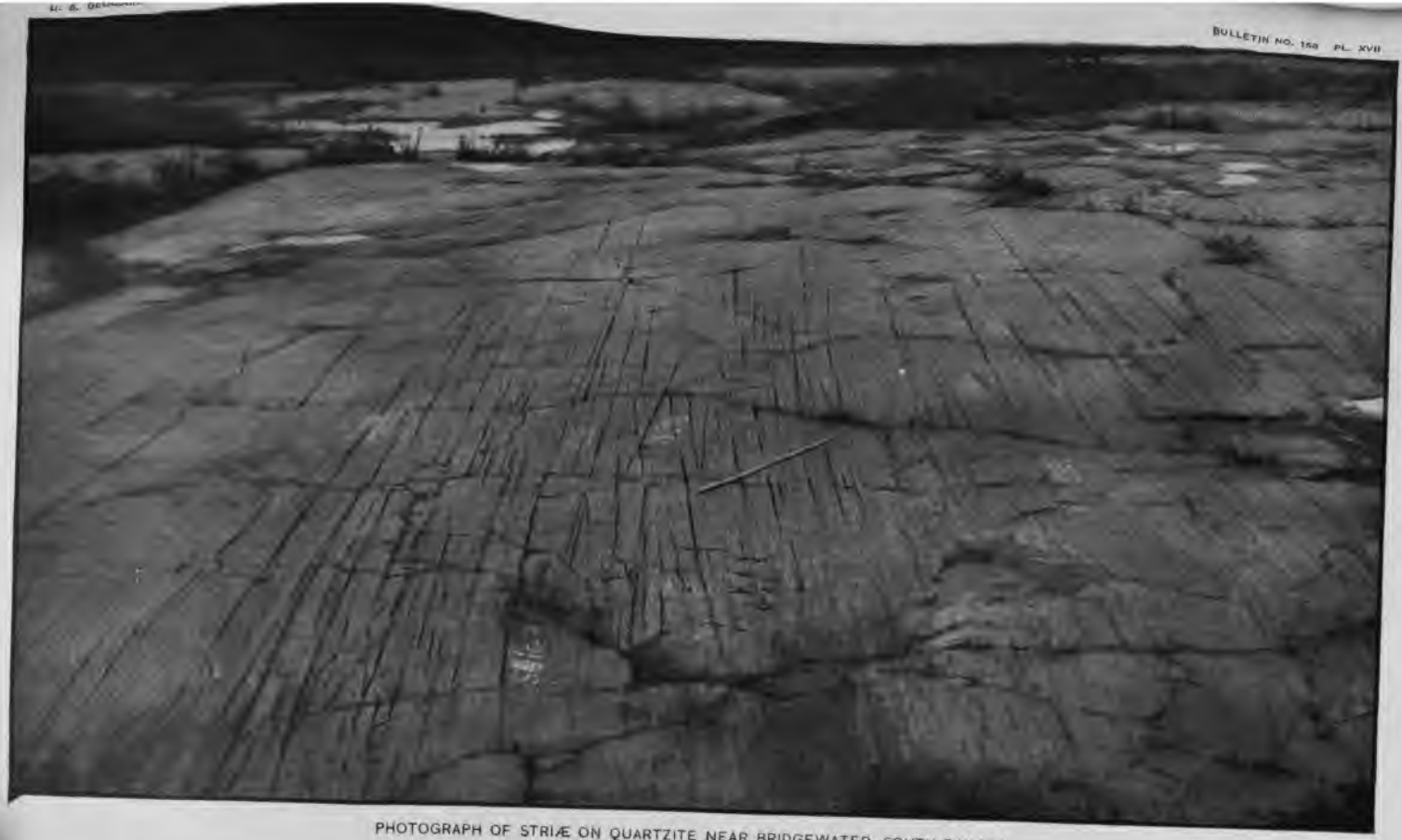


Fig. 30.—A gouge from quartzite exposure, near Bridgewater, South Dakota.



PHOTOGRAPH OF STRIÆ ON QUARTZITE NEAR BRIDGEWATER, SOUTH DAKOTA.

long was noted, and they occur of all sizes from that down to an inch in width. A roche moutonnée about 10 feet high and with several nondescript figures pecked upon its surface, stands by the creek near the center of the valley. Toward the westernmost exposure of the quartzite is a peculiar spoonlike gouge in the rock, evidently formed by the ice, at least smoothed and shaped by it. Its edge toward the north is quite complete, sharply defined, and curved like the point of the bowl of a spoon. Its southern edge is lost in the lower surface surrounding. The portion corresponding to the bowl of the spoon is regularly but slightly concave. The outer surface of a surrounding rock rises gently toward the rim before described. The subjoined sketch illustrates it better than words (fig. 30).

CHAPTER V.

TERRACES OF THE MISSOURI AND BIG SIOUX, AND HYDROLOGY OF THE REGION.

These have an important bearing upon the glacial history of the region, as they record more or less clearly the variations in level of streams attending the Glacial epoch and subsequent to it. They form perhaps the clearest evidence attainable in our field concerning the movements of the earth's crust and the meteorological conditions during the epoch. This evidence is the more valuable because it is in great measure independent of glacial deposits.

TERRACES OF THE MISSOURI AND ITS TRIBUTARIES.

These readily arrange themselves in three groups: The silt terraces, the lower bowldery terraces, and the higher bowldery terraces.

SILT TERRACES.

The silt terraces are chiefly distinguished by the fineness of their material and their markedly lower elevation. They do not rise anywhere higher than 100 feet above the present stream, and are usually much lower. Although covered with silt, they are not entirely composed of it, but often—especially the higher ones—are composed largely of Cretaceous clays in situ.

The survey of this group of terraces has been necessarily very incomplete. The number of observations taken is far from sufficient to prepare the way for a thorough discussion of them. The attention of the writer has been more turned to the bowldery terraces, which are more intimately connected with glacial phenomena. In general it may be said that there are two silt terraces which lie above high-water mark of the present time and which may be traced at most points favorable for their preservation. The difficulty of correlating them arises from their higher elevations in the vicinity of tributaries and the occasional interpolation of subordinate terraces.

At the Great Bend (Pl. XVIII) the higher terrace upon the right side of the river lies from 90 to 100 feet above low water. It is extensively developed in the bend; in fact, with the lower silt terraces it occupies the whole area of the bend north of its neck. This bend describes a circuit of 30 miles, returning to about 2½ miles from its beginning. At this locality is well illustrated the principle that a continually cutting stream forms a slope on the inside of a bend, which shows no break

GREAT BEND OF THE MISSOURI RIVER FROM THE EAST.

vvv A neck of Pierre clays, which, if cut through, would shorten the river 20 miles. v Missouri River. vv Bowldery terrace.

unless the course of the stream is at some point turned against it. Hence we find that this upper terrace grades down insensibly to the lower terrace in this slope, which is 7 or 8 miles in length. On the eastern side of the neck, where the measurements already given were taken, the lower silt terrace is from 30 to 70 feet higher than the river, while the present flood plain is only 10 to 18 feet above. On the opposite side of the river the higher terrace extends as a plain from 2 to 3 miles in width from the Great Bend to Crow Creek Agency and beyond. Its elevation above the river at the upper end is from 90 to 108 feet. Near Crow Creek Agency, where Soldier Creek enters from the northeast, it is from nearly 110 to 200 feet, while the bottom lands upon which the agency buildings are located is about 15 feet above the river.

At Chamberlain the lower terrace, upon which the town is built, is well represented, and shows, away from the mouth of American Creek, the Niobrara chalkstone occupying most of its height. It slopes from about 70 to 50 feet. Along its outer edge are a series of short, sandy spurs which rise to 125 feet. They may be part of a delta of American Creek. The lower terrace is narrowly developed along American Creek. Across the river, above Chamberlain, we again find the higher terrace well developed, from 40 to 70 feet in height, and traces of lower terraces also occur.

At Lower Brule Agency a lower terrace, about 45 feet in height, is well developed, the upper terrace being traceable also north of American Crow Creek, and back and south of the agency it is from 60 to 70 feet in height. Lower than the terrace upon which the agency is situated is a narrow flood plain, covered at high water. The higher terrace may be traced down the river as follows: It is faintly developed below the mouth of White River at an elevation of 50 feet. Opposite Brick Kiln Buttes it is narrowly developed and is about 80 feet high. Below the mouth of Snake Creek a high terrace appears sloping from a rather indistinct line about 150 feet above the river down to 50 feet, where it ends in a conspicuous edge. This is probably to be attributed to the rapid cutting down of the lower bowldery terrace through the narrows above Wheeler. At Mill Head Point, about 10 miles above Wheeler and on the opposite side of the river, it is about 75 feet in height. It is traceable north upon the opposite side of the river, and 2 or 3 miles south on the same side. At Wheeler there is a terrace upon which the town is built, about 45 feet above the river. The fine terrace upon which Fort Randall is built is from 30 to 35 feet above the river. At Niobrara the new town is built upon an extensive terrace about 25 feet above the river. No purely silt terraces higher than from 15 to 20 feet are noticed along the river farther south.

The lower terrace is represented again west of Brick Kiln Buttes at 30 feet and at the same level at Rosebud Landing. Below the mouth of Snake Creek it is not represented, unless in a broad bottom sloping from

about 25 feet down to about 10 feet. At Mill Head Point it is sharply shown at 45 feet. At Wheeler a terrace of considerable width rises about 18 feet and continues some distance eastward along the north bank of the river. A similar terrace, though narrowly developed, rises about 15 feet at Fort Randall, and is much wider on the opposite side of the river at White Swan. Farther down this seems to disappear or to be indistinguishable from the flood plain, which at Niobrara rises from 10 to 15 feet above the river, and about the same height farther down. This lower terrace is almost purely sand and dark loam; the higher terrace, as before stated, frequently has a Cretaceous base, and at some points, as at Wheeler and Fort Randall, considerable gravel and bowlderets are found in its lower portion.

LOWER BOWLDERY TERRACES.

Just north of the narrowest portion of the Great Bend rises a high, broad, butte-like hill. To the north it is bounded by the silt terrace already described. At the south a low ragged ridge of Cretaceous clays connects it with the main bank. Its surface, where least eroded, is quite even. It rises 235 feet above the river. Its whole upper surface is covered with bowlders and gravel mixed with yellow clay.

With a glass the hills to the northwest across the river were discovered to be also bowlder clad. Upon the east side of the bend the highland, curving sharply up against the river, shows no drift. No trace of bowldery hills similar to the one described is found till Soldier Creek is crossed, north of Crow Creek Agency. There a range begins which extends southeast across Campbells and Elm creeks to the vicinity of Crow Creek. These hills are more or less detached from the highland north by erosion. East of Campbells Creek they rise to 320 feet above the river. A well-defined bowldery terrace was noticed along Boxelder Creek 12 miles farther east, rising to the height of 125 feet above the stream. It is estimated to be 15 or 25 feet above the bowldery terrace east of Campbells Creek. South of that point this terrace is remarkably developed about the junction of Boxelder Creek with Crow Creek. It was also examined between the lower courses of Crow and Smith creeks, where it is mostly a barren plain of gravel.

In the vicinity of Chamberlain the extensive series of old channels and terraces which have been noticed in our consideration of the Red Lake region are found at a height of 200 feet above the river. This includes an old channel cutting across the northwest corner of T. 103 R. 71, leaving an ancient island west of it, and also the channel from American Creek southwest to the Missouri, in which lies Red Lake (Pl. XV). At about the same level is a broad, well-developed terrace lying along the north bank of the Missouri for 2 or 3 miles above its junction with White River. Along American Creek above Pukwana is an old lake bed at the same altitude, which is probably a portion of the old Red Lake channel. The terraces and channels show much gravel in

their upper portion, though covered with 10 or 15 feet of loess-like silt. An imperfect exposure in a ravine northeast of Ancient Island before mentioned, which is opposite Lower Brule Agency, is as follows:

Exposure northeast of Ancient Island, South Dakota.

	Ft.	In.
Gravel and sand, horizontally stratified	8	0
Laminated clay, showing ripple marks	1	2
Gravel and sand, arranged in short crescentic patches, showing oblique stratification (torrential)	10	0

This exposure is about 50 feet below the bottom of the old valley, and does not, therefore, include the covering of silt observed elsewhere.

In the vicinity of Chamberlain, also, the prevalent altitude of the bluffs along the river is from 325 to 350 feet. Their tops are quite uniform and little eroded. They are capped with 40 to 50 feet of drift, which passes into a layer of loess probably from 5 to 15 feet in thickness. The bluffs, across the river especially, have the appearance of a terrace. North of American Crow Creek a bed of gravel was found capping the edge of the terrace-like bluff 315 feet above the Missouri. It corresponds in level to the gravelly drift already mentioned as quite extensive on the south side of that stream. The top of Ancient Island, opposite Lower Brule Agency, rises 300 feet above the river. Between the lower course of the White River and the Missouri extends a silt-covered plain which averages about the same elevation. A terrace occupying the first bend in the Missouri to the south, and also a portion of the second in the same direction, is estimated to be at the same altitude. The lower gravelly plain south of White River seems to be only a little more elevated (350 to 400 feet), and probably belongs to the same formation. Perhaps some of it is a little more ancient.

Along the narrow channel directly southwest of the Bijou Hills I failed to observe any trace of this terrace, but west and northwest, back of the silt terrace already mentioned, it is widely developed as a sloping terrace from 95 to 175 feet high. It presents the usual features of 10 or 15 feet of loess-like silt above a heavy deposit of bowlders and gravel. In the valley of Pratt Creek, near its mouth, and developed extensively along the Missouri, is a bowlder-topped terrace 330 to 360 feet above the latter. A view of it from the south led to the belief that it was originally connected with a high terrace at Mill Head Point, which rises 250 feet above the river and rapidly declines toward the south. This latter terrace exhibits a remarkable quantity of bowlders in its upper portion, the coarseness of material apparently diminishing down the stream. Its structure is finely shown by a ravine crossing it a little below Mill Head Point. Its upper surface was originally covered with 10 to 15 feet of loess-like silt, which has been removed near the edges and along the ravines.

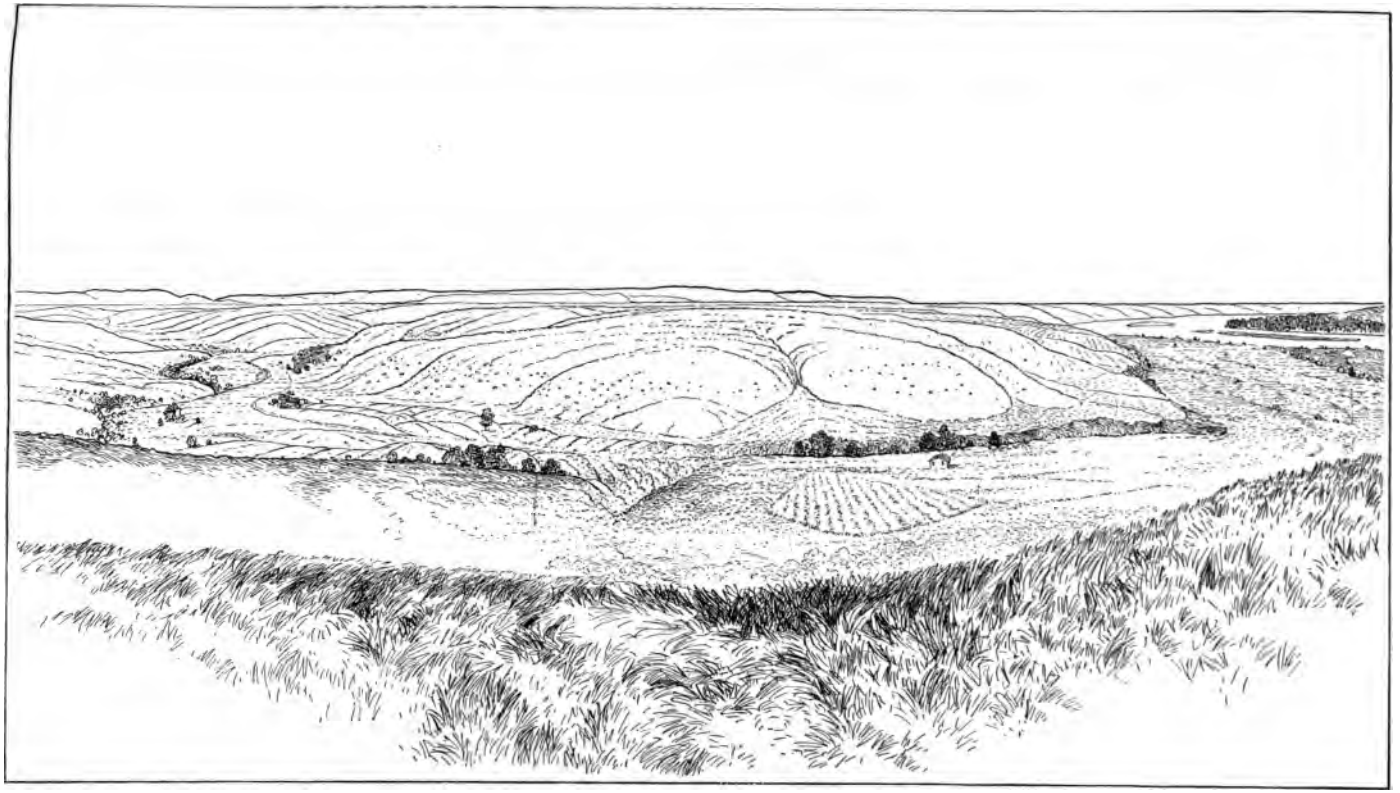
At Mill Head Point there is an extensive bowlder bar, reaching well out into the river, which at that point runs like a mill race. I was

informed that the river survey developed the fact that the river about 2 miles north of Wheeler was paved with bowlders.

Back of Wheeler is a broad terrace rising at its southern edge about 150 feet above the river. This presents a deep gravel bed, with bowlders in its upper portion and covered with loess-like silt about 10 or 15 feet in depth. North of Fort Randall, at the junction of the Andes Lake Outlet with the Missouri, a broad, sloping terrace lies at an altitude of 120 feet at its inner edge (Pl. XIX). Farther back it connects with the mouth of Andes Lake Outlet at the altitude of 200 feet. In this terrace the Cretaceous shales rise to the height of 90 feet. At Greenwood the terrace upon the north side of the river at its edge rises to an altitude of about 180 feet, presenting characters similar to those already mentioned. This terrace continues, with a breadth of from 2 to 4 miles, along the north side of the Missouri to the mouth of Chəteau Creek. It presents a beautiful fertile plain, quite even except where traversed by the three or four creeks which flow in deep, narrow valleys. The edge of the terrace back of Greenwood is 175 feet high; east of the creek near by, 140 feet, and 6 or 7 miles east in a similar locality, 200 feet. The remote edge of the plain east of Grass Lake Outlet is 240 feet, and about 5 miles northeast of Greenwood, where the ancient bank rises abruptly 75 feet above it, it is 250 feet above the river to the south (Pl. XX). North of Running Water this terrace fills the bend in the Missouri from the mouth of the Niobrara to Springfield, with an altitude quite uniformly of 200 feet. It constitutes the first bench north of the town of Niobrara, more than a mile in width, and is continued up the Niobrara River, first in the sharp south bend near its mouth, then extensively on the south side of the river up for 15 or 20 miles. This terrace is also well developed along the east side of Bazile Creek.

Farther east, along the south side of the Missouri, the surface has been so modified by erosion that little trace of terrace formation could be expected and none was noticed. In the valley of Weigandt Creek southeast of Herrick, Nebraska, there is an extensive terraced surface rising at some points about 325 feet above the Missouri. There was much difficulty, when first examined, in correlating it with other deposits along the Missouri. But further study led to the satisfactory conclusion that it was formed by Weigandt Creek and its tributaries. It rises from 175 to 200 feet above that stream. It presents the usual features of a gravelly terrace, with the silt covering scantily formed. Similar deposits are found along the neighboring stream, called Beaver Creek.

At Yankton, on the north side of the river, the outer slope of the moraine, as was noticed in the valley northwest of the town, is quite gravelly about 130 feet above the river. Passing north from Yankton 3 or 4 miles, we reach a broad terrace south of another of the numerous Beaver creeks. This is at an altitude of 120 feet above the river and connects with the broad valley south of Lesterville. Though the



LOWER BOWLDERY TERRACE, OPPOSITE FORT RANDALL.

terrace seems mostly covered with pebble clay or loess-like silt, on the slope south of Utica considerable gravel was noticed.

At Vermilion the principal terrace, which is 6 or 7 miles wide and extends eastward to the Big Sioux, is about 80 feet above the river. It shows its structure to be pebble clay, with its upper surface eroded and capped with silt.

Below the mouth of Floyd River, near Sioux City, is a terrace 115 to 150 feet high. It is composed of coarse sand below and of loess-like silt in the upper two-thirds; no bowlders.

In the vicinity of Herman, Nebraska, a terrace begins which continues past Blair to De Soto, about 10 miles in length and in places nearly 2 miles in breadth. This rises 100 feet above the river. At Fort Calhoun a similar terrace extends 5 or 6 miles. An obscure one about 60 feet in height is found at Omaha. At Bellevue, north of the mouth of the Papillion River, is another well-developed terrace from 60 to 70 feet above the river, and a similar one is found below the mouth of the Weeping Water at Wyoming.

We have already briefly described the extensive terraces along the Platte and Elkhorn rivers which rise to a level of 80 feet near their junction.

The valley of the White River approaches that of the Missouri in size, and is likewise mostly excavated from the Cretaceous clays. The alluvial bottoms rising about 20 feet from the bottom of the river form a more prominent feature, usually occupying most of the space in the deep bends in the river. Rising abruptly from this alluvial plain are bluffs of shaly clay over 100 feet in height. At an altitude of about 130 feet is a well-defined gravelly terrace containing mostly western gravel. This seems to be excavated out of the Cretaceous, which appears again back of it and rises abruptly to the edge of a higher terrace about 200 feet above the stream. This terrace in one place shows alluvial deposits 30 or 40 feet in depth, exhibiting loess-like silt below, including about its middle a dark carbonaceous layer like an old soil. It is capped above, first with gravel, then with bowldery clay, which slopes with a gentle rise backward from the river to a height of about 260 feet. At the height of about 325 feet another gravelly terrace appears, containing northern erratics and limestone and granite bowlders like the last. This seems to be continuous with the sheet of gravel south of the river, which has already been described.

COMPOSITION OF LOWER BOWLDERY TERRACES.

Thus far we have treated only of the external appearances of the lower bowldery terraces. We now proceed to give what light has been found concerning their internal structure and composition. There has already been given an imperfect section, which is found opposite the Lower Brule Agency. Apparently, although not certainly, the pre-

vailing structure is somewhat as follows: Ten to 15 feet of silt, passing abruptly into stratified sand and gravel, which is coarse and bowldery near the top, and finer and more evenly stratified below, the depth of the sand corresponding to the inequalities of the deposits below. In some cases the upper portion of the gravel is more or less occupied with till of reddish or yellowish color.

At White Swan and below, the Niobrara chalkstone and Pierre clays rise over 100 feet, forming a very substantial base for the terrace. Above these there seems to be a heavy body of till, but it is nowhere well exposed. Seven miles east of Greenwood the Cretaceous clays appear to rise over 150 feet, and shallow exposures exhibit red till above for 30 or 40 feet, and a mantle of silt of variable thickness over the whole. Between that point and the mouth of Choteau Creek the terrace is much eroded, but little or no trace of sand is found. The phenomena of soil and topography seem best explained by supposing that the body of the terrace is largely composed of Pierre clay.

Opposite Niobrara is a very complete exposure of the terrace, which is as follows:

Exposure opposite Niobrara, Nebraska.

	Feet.
Loess-like silt	10–12
Red clay, imperfectly stratified, which abounds in pebbles and bowlders	35
Fine sand, thinly stratified, with no trace of northern erratics	55
Imperfectly exposed	45
Niobrara chalkstone	70
Level of the river.	

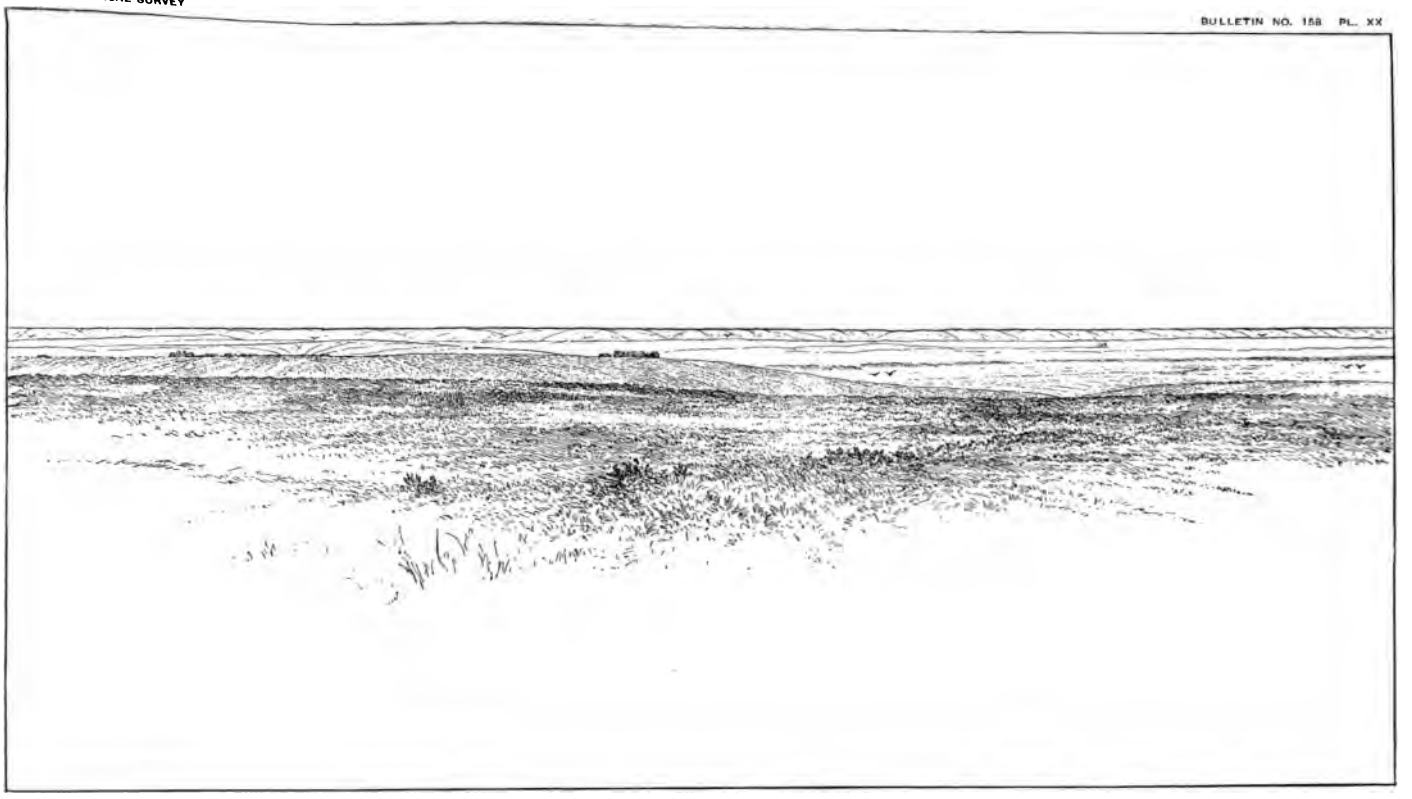
The sand in this section seems identical in structure and composition with that observed at the Devils Nest and north of Coleridge. While there it is at an altitude of from 350 to 400 feet above the river, here it is below 150 feet. Still, its freedom from northern erratics would seem to indicate its pre-Glacial deposition. Moreover, it has less altitude than the Cretaceous rocks in this same terrace farther west, and the red clay at this point seems to correspond to that at Greenwood, both in altitude and in time of deposition. On the whole, therefore, it seems not improbable that the sand was deposited by the Niobrara, possibly in Lake Cheyenne, before the advent of the drift.

At Vermilion a combined section is as follows:

Section at Vermilion, South Dakota.

	Feet.
Loess-like silt, straticulate	15–20
Till, eroded on top, yellow and compact above, and composed of irregular patches of gravel, sand, and red and blue till below	40–50
Unexposed	20
Level of the river.	

This composition may be referred to material brought down by the Vermilion River, at first laden with ice blocks, or in part to the direct action of the extension of the Vermilion lobe of the ice sheet. On either supposition a deep preglacial valley at this point must be postulated.



LOWER BOWLDERY TERRACE, FROM THE OLD BANK NORTH OF GREENWOOD, SOUTH DAKOTA

v Missouri River. v v Broad, shallow, channel-like slough.

Three miles southeast of Blair the structure of the terrace is finely exposed in a number of deep ravines which cut through two-thirds of its height. They show nothing but rearranged loess, with an occasional thin streak of gravel in its lower portion. A similar composition is evidently true of the terrace at Fort Calhoun and also at Bellevue, except that its base is occupied by Carboniferous limestone. In each case the composition is referred to the numerous high loess bluffs in the close vicinity and along the river above, with comparative absence of drift.

The terraces along the Platte and Elkhorn have apparently very uniform structure, which consists first of silt, then of fine sand, passing below into fine sand and gravel. The evidence from deep driven wells shows that below the first gravel is a thick continuous layer of clay, below which is another heavy deposit of gravel. These lower layers extend underneath the whole valley so far as is known. Northwest of Fremont an exposure showed as follows:

Exposure northwest of Fremont, Nebraska.

	Feet.
Loess-like silt	30–40
Fine sand	30–40
Unexposed	20

Level of bottom land, which is probably 10 to 20 feet above the level of the river.

North of North Bend was found from 5 to 15 feet of silt, according to the undulations of the surface, and sand rising from 75 to 80 feet above the river. The upper surface of the terrace shows gouges and imperfect channels, as if formed by strong currents.

From the foregoing presentation, particularly if reference is made to the table on a subsequent page, it appears that, above the narrows above Wheeler, there are two series of terraces mentioned under this head, one 100 to 150 feet above the other; also, that they come together below Wheeler. That they do not mark stages of the river as widely separated as their altitudes might seem to indicate may be inferred from the following considerations: The lower seems in places to be continuous with the bottom of old channels, as that of Red Lake, and east of Ancient Island, as though it corresponded to the bottom of a stream, while the upper series seems to slope gradually up into the surrounding country, as though it might mark the margin or flood plain of the ancient stream.

HIGHER BOWLDERY TERRACES.

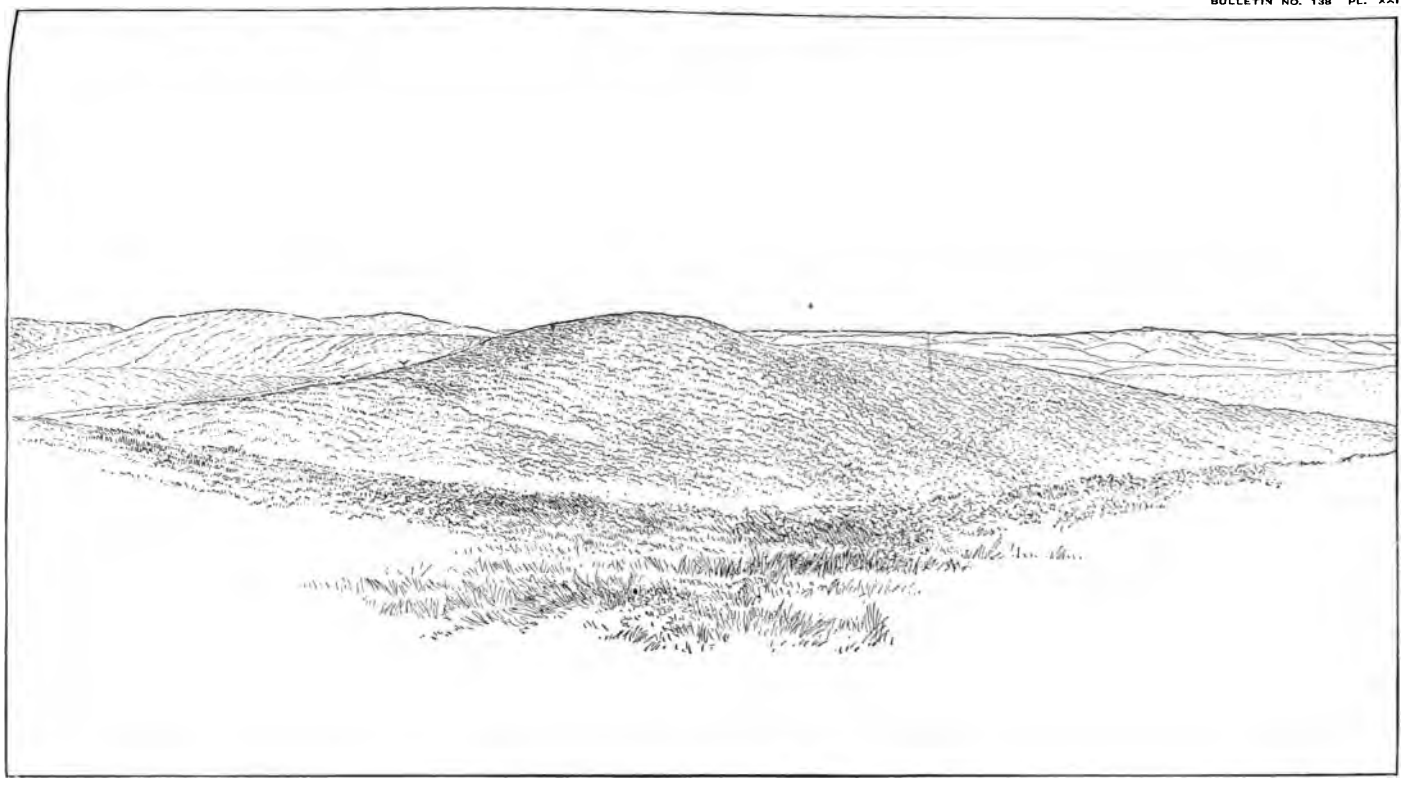
These are the least easily recognized of all. This is not surprising when we remember that they are much the most ancient. Their high elevation, together with the unusually loose character of the strata upon which they rest, lead to the same result. Moreover, if the river was largely lacustrine when they were formed, as we are disposed to believe, its existence will only occasionally be evidenced by deposits adjacent to the present stream. They may have the various forms of

beach or bar and delta as well as river terrace, according to circu stances. Little time has been given to their study, and the few obs vations incidentally made are given for what they may be worth.

Near the summit of the high hill south of the Red Lake Outlet, the side next to the Missouri, gravelly deposits were noticed at t altitude of a little more than 425 feet, which may be correlated w the higher portion of the gravelly plain just mentioned. Along Sna Creek, near its mouth, an extensive sloping terrace is found, with usual bowldery gravel covered with silt and rising 330 to 417 feet abc the river. Besides these in the Red Lake region, we have nothing suggest a terrace deposit below the trace of a water level around t Bijou Hills and the bowldery and gravel-topped hills 5 or 6 mi southwest of the mouth of White River, which are believed to ma the highest reach of the Missouri since its beginning.

Five or 6 miles east of Wheeler the outer face of the moraine sho at the different points, the gravelly edge of a terrace at an altitude over 400 feet. At Fort Randall, on the south side of the river, i well-defined terrace, with its inner edge having an altitude of 415 fe Northeast of Fort Randall, near the moraine, is a similar well-defi edge of a terrace 420 feet above the river, which slopes gently up 450 feet. On the north side of the river northeast of Greenwood surface is too low to exhibit any trace of a water line at this le Opposite the mouth of the Niobrara the outer surface of the hill wh forms a fragment of the moraine shows, a little below the sumn abundant gravel and sand at an altitude of about 400 feet above river.

Between the Niobrara and Bazile Creek and along the Missouri e of the Bazile is found a wonderful development of gravel capping older deposits in a terrace-like form at an altitude of 415 to 475 f above the river (Pl. XXI). It is observed to extend several mi south, and, as has been described under the head of the loess regi there is abundant evidence to show that this gravel formation exte underneath the loess indefinitely. It may not be called a terrace, the gravel exposed along the north edge of the loess, between it a the fine sand below, seems probably to belong for the most part entirely to the same formation as the terrace described. Toward east side of the Santee Reservation the gravel seems to have been s arated into an upper and a lower member. The lower portion exte like an eroded terrace at the height of 390 feet. We have provisi ally ascribed this phenomenon, on another page, to undermining. will be remembered that this gravelly drift extends, with declining vation, nearly to Dixon County. So far as has yet been discovered trace of terrace at a corresponding altitude has been noticed be that point. It corresponds in elevation with gravel beds obser several miles up the Niobrara and with another near Plainvi Nebraska. Both of these show only western gravel.



UPPER BOWLDERY TERRACE SOUTHWEST OF SANTEE AGENCY, NEBRASKA.

v v Volcanic ashes in road.

Table of heights of the terraces along the Missouri from the Great Bend southward.

[*r* indicates the right bank, and *l* the left.]

Locality.	Silt terraces.	Lower bowldery terraces.	Higher bowldery terraces.
	Feet.	*Feet.*	*Feet.*
In the Great Bend *r*	10, 18, 30–70, 90–100	235	.....
East of the Great Bend *r*	90–100	.....	.....
Crow Creek Agency *l*	15, 110–150	200–250, 320	.....
Two miles above Chamberlain *r*	8–10, 30–70	325	.....
Chamberlain	15–30, 50–80, 120–125	325	.....
Three miles south of Chamberlain *l*	75–80	200, 350	.....
North of American Crow Creek *r*	*a* 70–80	315–320	.....
Lower Brule Agency *r*	10, 20–40, 60–70	.....	.....
Ancient Island *l*	.....	200, 300	.....
Above mouth of White River *r*	*a* 50	300	.....
South of mouth of White River *r*	*a* 10	250	350–400 510
South of Red Lake Outlet *l*	.....	*a* 200	450–460
West of Brick Kiln Butte *r*	15, 30–50	90–175	.....
Bijou Hills *l*	.....	.....	590
Rose Bud Landing *r*	15–20, 65–75	.....	.....
Near mouth of Snake Creek *l*	10, 20, 50–150	330	417
Near mouth of Pratt Creek *l*	90–126	300–350	.....
Mill Head Point *r*	45, 85	200–250	.....
Wheeler *l*	5, 9–18, 45, 85–105	*a* 135–175	.....
Four miles east of Wheeler *l*	40–75	.....	410–430
Andes Outlet *l*	*a* 10, 25	125–190	350
Fort Randall *r*	15, 30, 40–45	.....	415
Greenwood *r*	.....	180–240	.....
6 miles east of Greenwood *l*	.....	200–250	.....
Opposite Niobrara *l*	.....	200	*a* 400
Niobrara *r*	5, 10, 20	180–210	415–450
Devils Nest *l*	10, 30	.....	450–475
Yankton *r*	10, 25, 70	120–140	.....
Vermilion *l*	10–15, 20–25	80–100	.....
Blair *r*	10–20	90–110	.....
Calhoun *r*	*a* 10	*a* 100	.....
Bellevue	*a* 10, 20	50–70	.....

a Estimated.

The different levels under the head of "lower bowldery terraces" probably do not mark two stages of the Missouri, widely separated, as might be inferred, for the upper one appears to have been marking generally the surface or flood plain of the river, while the lower in many cases seems from its configuration in some places to record the bottom of the stream.

TERRACES ALONG THE BIG SIOUX.

As the Big Sioux is the counterpart of the Missouri in its relation to the moraine, so we should reasonably expect a system of terraces along it resembling that already described along the Missouri. From its lower altitude, more open valley, and less volume of water, we are prepared to anticipate lower floods and less corrosion, and consequently less difference in altitude between the terraces. Another important circumstance acting in the same direction is found in the greater hardness of rocks over which it flows. But without anticipating too much, we will proceed to examine the few traces of terraces which have been noted. It should also be acknowledged that the examination of this stream has not been so complete as in the case of the Missouri.

Above Sioux Falls the depth of the immediate valley of the Big Sioux is from 80 to 100 feet below the adjoining hills. Its sides are less abrupt, and the whole appearance is that of a stream in its middle course. This may be explained by the check given to its erosion by the ledge of Sioux Falls and higher up by the rock at Dell Rapids.

SILT AND LOWER BOWLDERY TERRACES.

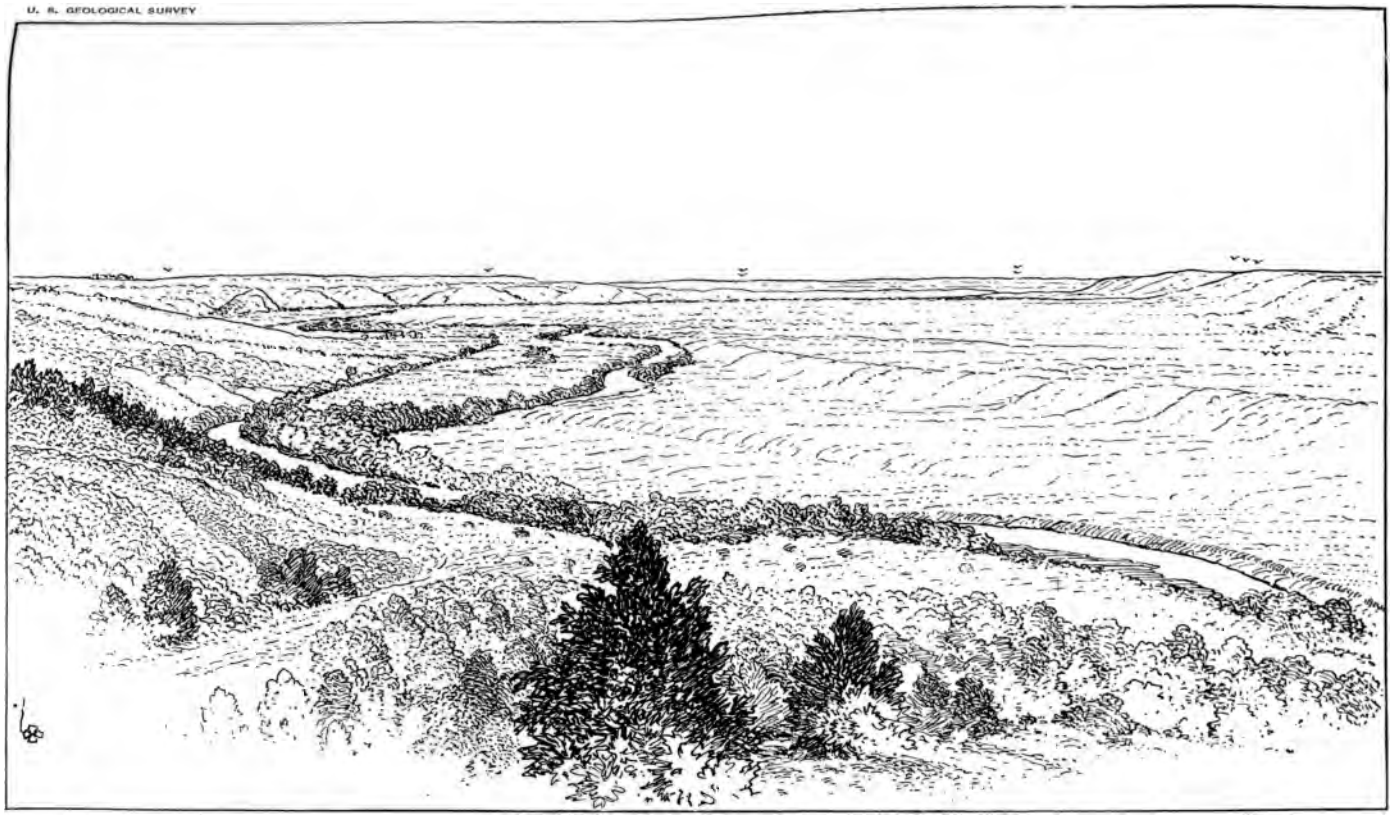
At Egan, besides the immediate flood plain, which is quite low, is a terrace along the north side of the valley with its inner edge about 30 feet above the stream. About a mile and a half northeast of Egan, in the edge of a gravelly terrace, the following section was noticed, beginning 30 feet above the river:

Section northeast of Egan, South Dakota.

	Feet.
Soil	1½
Loess-like clay, with small pebbles and chalky points	1
Roughly and indistinctly stratified gravel, its upper half clayey, yellowish tint; lower, more sandy	7½
Coarse sand, with scattered pebbles, obliquely stratified, in eight layers from 1 to 8 inches in thickness	5½

At Sioux Falls, as has been before stated, there is a very gravelly terrace extending from near the top of the falls down the river to the vicinity of Brandon, which is shown by railroad levels to be about 80 feet above the stream at that point. A little below the mouth of Split Rock River the elevation of the wide bottom along the east side of the Big Sioux is from 35 to 50 feet above the stream. Its altitude here is possibly due to ledges of red quartzite exposed a short distance below. At Kruger's mill, about 6 miles northeast of Canton, the terrace lies on both sides, but best developed on the east side, about 50 feet above the stream, and presents an interesting deposit of sand and gravel in its upper portion. The gravel presents the flow-and-plunge structure, and through it a fault was noted of a few inches throw extending vertically. At Canton several alluvial terrace edges are shown along the sides of

U. S. GEOLOGICAL SURVEY



BIG SIOUX RIVER NEAR FAIRVIEW, SOUTH DAKOTA.

v Principal moraine. $\overset{v}{v}$ Plain inside. vv Higher bowldery terrace. $\overset{v}{vv}$ Lower bowldery terrace.

e valley. There are but two, however, that are clearly distinct; ie first is from 10 to 20 feet above the stream, the second about 40 et. The edge of the plain northwest shows a terrace edge, usually ith much gravel at exposed points. This is about 125 feet above the ream.

In the narrow portion of the valley between Beloit and Fairview Pl. XXII) is found a very interesting terrace of unusually bowldery haracter, which seems to correspond with the plain northwest and ist north of the north end of the moraine, which occupies Highland ownship. This plain, it will be remembered, corresponds in height ith, or is a continuation of, the plain west of Canton, upon which orthing and Lenox are situated. This terrace, 2 miles northwest of airview, is about 90 feet above the stream, and presents a furrowed ppearance, as though eroded by streams flowing in the same direction the present stream. These furrows and low places correspond with second terrace, which is about 45 feet above the river. Opposite airview the whole surface has declined to that altitude. Back of airview a faint terrace edge was noticed at a height of 50 feet. ortheast of Austin this same high terrace is traced, presenting simi- r characters, at an altitude of 60 to 75 feet above the stream. Just rth of Hudson, on the west side of the Big Sioux, is a gravelly ter- ce utilized by the railroad company as a gravel bed. Its upper sur- ce is about 60 feet above the stream. The surface of this terrace pears to decline rapidly toward the south. It is not difficult to rrelate this series of terraces with the lower bowldery terraces along e Missouri. A well-developed gravelly terrace is found on the south le of the valley above Lake Madison, rising about 80 feet above the ce, and along east of Skunk Creek, southwest of Dell Rapids, a ter- ce, apparently of silt, rises to the height of 40 feet.

HIGHER BOWLDERY TERRACES.

The first and most remarkable examples of these are the high gravel ls northeast of Sioux Falls which, as was stated on a preceding page, e about 210 feet above the stream. Near Kruger's mill, it will be membered, there is a high terrace, with its inner edge about 160 feet height, while farther south an exposure showed a stratified structure ce that of a terrace at the height of 108 feet, and a gravelly line at a ght of 180 feet. West of the stream a very bowldery edge, like that a terrace, was noticed at a height of 120 feet, which is a little above e plain west. East of Canton the gravelly deposits shown in rail- ad cuts extended from about 100 to 175 feet above the stream. North Fairview, and also east of the same place, a gravelly edge appears the side of the bluffs at the height of from 200 to 220 feet. West of alliope the hilltops, which are doubtfully referred to a terrace, are out 125 feet above the stream.

TERRACES ALONG OTHER STREAMS.

There are few other streams in the field under consideration which are outside of the moraine. Those of this class in Iowa have not been studied with care, but most of them show high terraces of silt—second bottoms, as they are popularly called—which often serve as favorable locations for towns.

Striking examples of prominent terraces corresponding to those along the Platte and the Missouri below Sioux City have been noted along the Boyer at Dunlap and Logan, the Nishnabotany at Harlan and Atlantic, the Little Sioux at Cherokee, etc.

PRESENT SLOPES OF THE MISSOURI AND BIG SIOUX.

From railroad levels and the Government survey of the Missouri we obtain the following:

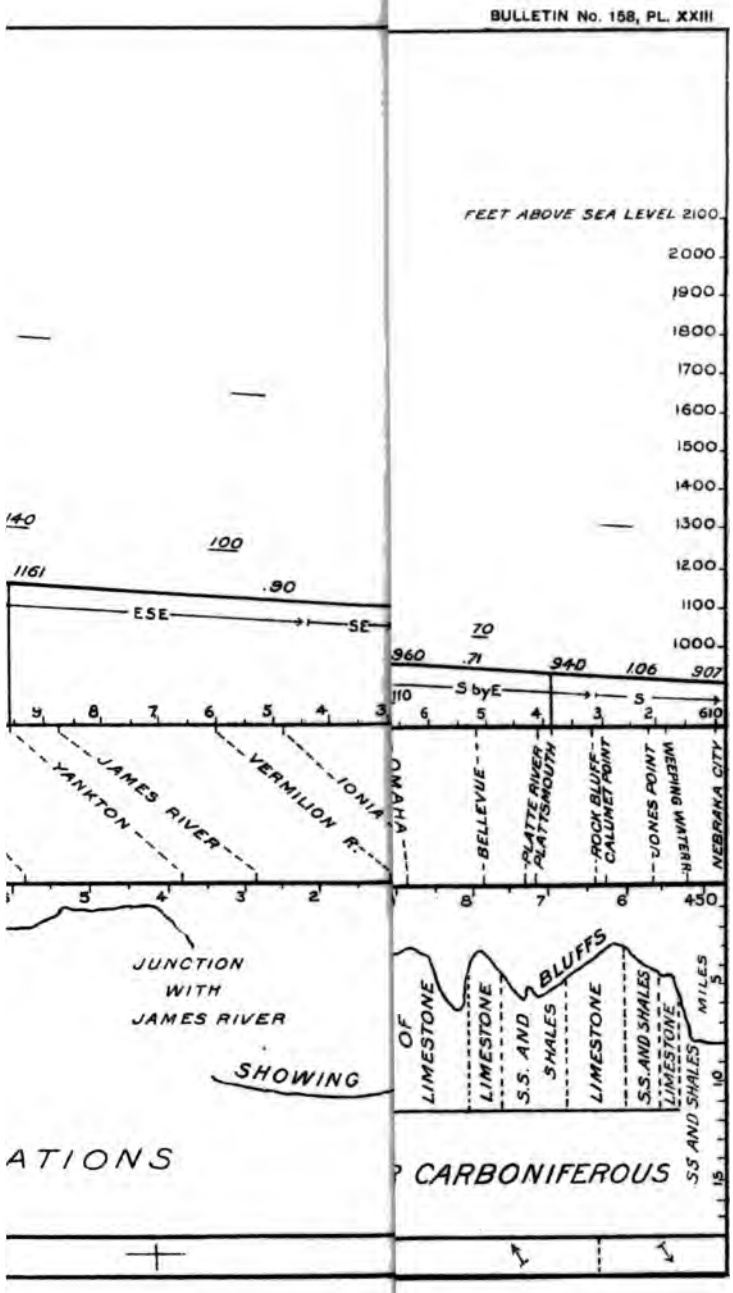
Low-water slopes of the Missouri and the Big Sioux.

	Feet per mile.
Missouri:	
Pierre to Chamberlain	0.97
Chamberlain to Niobrara	.93
Niobrara to Yankton	1.02
Yankton to Sioux City	.90
Sioux City to Blair	.87
Blair to Omaha	.81
Omaha to Plattsmouth	.71
Plattsmouth to Nebraska City	1.06
Big Sioux:	
Flandreau to Dell Rapids	2.26
Dell Rapids to Sioux Falls	3.46
Brandon to Hawarden	2.25
Hawarden to Sioux City	1.00

AGE OF THE TERRACES.

If we accept the prevalent view that the outer moraine marks the maximum extent of the ice in the second Glacial epoch and that the formations outside belong to an earlier epoch, it readily follows that what we have grouped under the head of "lower bowldery terraces" belong to the later time. Their fresh contour and their relation to the loess and extra morainic drift all harmonize with this view. Looking further, the twofold grouping of these terraces would correspond well to the outer and second moraines. The lower terraces would as easily be referred to the times of the third, fourth, and later moraines. Their silty character would result from their remoteness from the glaciers, much as is found to be true of the higher terraces below Sioux City, when the river had left the vicinity of the ice during its earlier and greater extension.

The higher bowldery terraces, according to the scheme adopted, would be referred to a time preceding the loess, probably the first subepoch of the earlier epoch.



TROUGH OF THE MISSO

More careful study of the terraces, especially after artificial exposures ve been multiplied by the settlement of the country, promises to be e of the most interesting and instructive fields in Pleistocene geology. e above is only a beginning of what may be done.

DIAGRAM OF THE TROUGH OF THE MISSOURI.

We have subjoined a diagram (Pl. XXIII) showing graphically the pe, width, depth, terraces, etc., of the trough of the Missouri River m Pierre to Nebraska City. Its data are derived from the reports of e Missouri River Commission, railroad levels, and personal obser- tions. Two things of interest are specially notable: One, the differ- ce in width above Yankton as compared with the portion below that int; the other, the close correspondence between the width of the ough and the softness of the geological strata corraded. The remark- le width of the trough from Sioux City to Blair is probably largely e to the assistance of escaping artesian waters from the Dakota rmation.

A similar diagram, somewhat abridged, showing similar facts for the issouri below Nebraska City, may be found in Report of Missouri eological Survey, Vol. X, 1896, p. 188.

WESTWARD ELEVATION OF THE REGION.

We have referred several times to a possible recent westward eleva- n of the region under consideration. We will now consider facts ich bear upon its amount, extent, and age. These will be of value, en if not found decisive.

Along the line between Mitchell and Chamberlain the slope of the face, where it is unaffected by local erosion, descends toward the t about 10 feet to the mile. This we may refer partly to the action the ice sheet; but comparing it with the opposite side of the valley re is left a considerable amount to be explained by some other cause n the erosion of the ice. Farther south we find the same slope pre- ling between Pratt Creek and the James River. We even find that plain between the Big Sioux and the Vermilion east of Parker is to 75 feet lower than the plain between the West Vermilion and olf Creek west of that place. The determination of the prevalent pe farther south in Dakota is rendered difficult by the occurrence of erlobular portions of the moraine. If we refer to the table of ele- tions along the moraine given in our first chapter we find them har- nizing with the idea of a considerable westward elevation.

Passing now into Nebraska we find, it will be remembered, the sur- e composed mostly of loess, which in its westward portion presents clearly defined and quite recognizable plateau. Upon this we may ke a number of elevations which will indicate very satisfactorily the neral slope of the country. Farther east, with a little care, the orig- al or prevalent level of the loess may be determined from the few

isolated remnants which appear to be the original surface. The following table presents the results of such determinations along lines extending east and west. The figures may be more relied upon in the western portion of the field because more closely connected with railroad elevations. In the eastern portion, though largely barometric, it is believed that they have need of only slight correction.

Slope in eastern Nebraska.

Locality.	Distance.	Slope per mile.
	Miles.	*Feet.*
Kimball to Mitchell	48	10
Northside to Emerson, Nebraska	30	6.6
Oakdale to Wisner (Elkhorn Valley)	57	5.9
Humphreys to Blair	70	5.5
Platte Center to Mapleville	40	6.3
Mapleville to Blair	30	2.7
Columbus to Fremont (Platte Valley)	47	5.5
Aurora to Utica	36	5.9
Hastings to Dorchester	68	6.5
Patterson to Sheldon, Iowa	14	1.5
Akron to Marcus, Iowa	33	1.6
South of Hillsdale to Creston	70	0

From this we learn: (1) That the James Valley and the Missouri below their junction mark approximately the axis west of which the western elevation is much more marked, averaging about 6 feet per mile. (2) That the slope east of that line is very slight, if anything. It amounts to about 1 foot per mile in northern Iowa, and may possibly be found to be less, for our observations are quite limited. Another reason for doubt lies in the fact that the elevation of the eastern edge of the loess has not been definitely determined, but it can not vary greatly from the figures given. (3) That the slope diminishes rapidly as it approaches the Missouri in eastern Nebraska, as is indicated by the slope between Mapleville and Blair.

A general view of the change of slope indicates that its axis follows approximately the boundary between the Cretaceous rocks and the older rocks. The Archean quartzites of Dakota seem to have been least affected. This axis, which is the eastern limit of the steeper westward acclivity north of our field, continues apparently up the James River through Brown County and then curving eastward around the head of Coteau des Prairies, extends into the valley of the Red River.

Date.—1. The relations of the drift to the volcanic ash stratum in eastern Nebraska and to the lacustrine beds in Mills County, Iowa, to say nothing of less definite beds pointing in the same direction, indi-

cate that during the Pliocene and on into the *Glacial epoch the western* elevation had not begun to affect materially the slope of the region under consideration. Farther west it may have considerably advanced before the advent of the ice.

2. The position of the ice sheet during the occupation of the principal moraine indicates little, if any, relative elevation toward the west. The westward pushing of the ice south of the Wessington Hills is difficult to explain if the slope of the land was as great as at present. The existence of the glacial lake around the Bijou Hills and above is more easily understood if the land was at a lower level than at present. Nevertheless, it is not fatal to the hypothesis to suppose the relative elevation to have been as great then as now.

3. The deposition of the loess, which we have conceived to be a fluviolacustrine formation, favors also a gentler slope than the present. The force of this argument would be somewhat weakened if it could be satisfactorily shown that the deposition of similarly fine material is consistent with considerable velocity in the depositing waters. We might then perhaps conceive the western portion of the loess to consist of the gigantic "alluvial fans" of the Niobrara, Elkhorn, and Platte, formed largely under subaerial conditions. Moreover, with an overloading of silt this would be more conceivable.

4. The deflection of the ice toward the east during the formation of the second moraine, together with the change of drainage about White Lake and Lake Andes, though perhaps not demanding, strongly favors the conclusion that the elevation had at that time become perceptible.

5. It will be noticed that the relation of the high terrace of the Platte River to the higher land in the vicinity of Fremont, Nebraska, suggests that the desertion of the old channel across Saunders County may have been due to its cutting through the divide which formerly separated the Platte from the Elkhorn, and that this was subsequent to the formation of the terrace. If the terrace was, as we have supposed, contemporaneous with the outer moraine, and the cutting through at Fremont was the result of an increased slope of the river, it follows that the elevation was still in progress after the occupation of that moraine, and may have continued indefinitely.

6. Another feature of the terraces points to the same general conclusion. Along the Missouri River between Monona County, Iowa, and the southern line of the State, there are no high terraces of importance on the east side of its present valley. There are a few points where the terraces along its eastern tributaries appear, but they do not project beyond the trend of the present bluffs. Along its western side, on the contrary, as we have already noticed, there are extensive terraces 60 to 100 feet high, found between Tekamah and Calhoun, between Florence and Omaha, and between Bellevue and the mouth of the Papillion, so also near the mouth of the Weeping Water. If no tilting had occurred, the converse should be true, for the rule that the streams in

the northern hemisphere erode more rapidly the right side valleys has few exceptions.

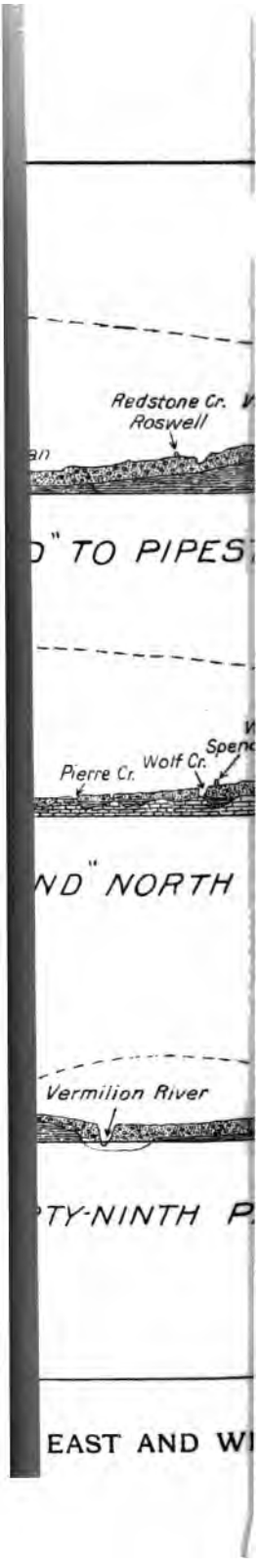
Whether the upward movement continues to the present is u The slight slope of the Missouri from Chamberlain to Sioux C seem to favor the idea that such is not the case, and yet the of the stream may possibly keep pace with the slow elevati may still continue. That river is so laden with sand that th ing of its real bed may be so masked as to be undiscoverable. erable light upon this subject in general may be derived from eral sections. Pls. XXIV and XXV.

NORTHWARD ELEVATION OF THE REGION.

In our tables of elevation marking the general level of there appeared a marked slope to the south. This is brought distinctly in the list of elevations, which is arranged for the l along north-south lines. While this feature is most clearly in Nebraska, it appears also in less degree in western Iowa the valley of the Big Sioux above Sioux Falls, and in the portion of the region within the principal moraine. The table will illustrate and impress these points:

Slope in western Iowa.

Locality.	Distance.	S
	Miles.	
Plainview to Humphreys, Nebraska	54	
Osceola to Fairmount, Nebraska	42	
Plainview to Fairmount, Nebraska	125	
Southwest of Coleridge to Northside, Nebraska	25	
David City to Dorchester, Nebraska	42	
Coleridge to Dorchester, Nebraska	127	
Blair to Louisville, Nebraska	35	
Louisville to Turlington, Nebraska	21	
Blair to Turlington, Nebraska	56	
Sibley to Marcus, Iowa	40	
Marcus to Hillsdale, Iowa	125	
Sioux City to California Junction (Missouri Valley)	70	
Missouri Valley to East Nebraska City	62	
Wentworth to Taopi, South Dakota	13	
Taopi to Hartford, South Dakota	13	
Wentworth to Hartford, South Dakota	26	
Airlie, Minnesota, to Larchwood, Iowa	38	
Lenox to Vermilion, South Dakota	37	
Plankinton to Grandview, South Dakota	23	


Redstone Cr.
Roswell
Pierre Cr.
Wolf Cr.
Vermilion River

The localities in the above table stand for the upland in their vicinity. urther information is afforded by the general sections, Pl. XXV.

From a study of this table we come to the following general conclu- ons: The region outside of the principal moraine has uniformly a neral slope toward the south. In the loess region this averages on e long slopes from 1.3 to 2.6 feet per mile. In the Coteau des Prairies gion it is from 4 to 5 feet per mile. Between the outer and the second raines there exists on the east a slope of 3.5 feet to the mile, but st of the James there is a rise southward of from 1 to 1.5 feet per mile m the line of the Chicago, Milwaukee and St. Paul Railway. This egularity may be connected with a slight increase of elevation of the ss summits from the vicinity of the Missouri south to the southern rders of Knox and Cedar counties, and be made to argue for the cent anticline, with its axis running east and west, near the Niobrara. en. G. K. Warren arrived at a similar conclusion from independent ata noted farther west.[1] This hypothesis may help to relieve two ther difficulties of some weight—the absence of the loess along the issouri north of the Niobrara at levels below its summit in Knox ounty, Nebraska, and the difference in elevation of the lower bowldery errace at Running Water and Vermilion, Dakota.

An examination of the James River Valley brings out the remarka- le fact that within the second moraine the general level of the valley s exactly horizontal in a north-south direction. From the vicinity f Mitchell to Columbia and beyond, for more than 140 miles, the varia- on in altitude according to railroad elevations (notice especially those f the Chicago, Milwaukee and St. Paul Railway) is scarcely 10 feet. etcher, Diana, Cavour, Redfield, Ashton, Aberdeen, Groton, and olumbia are all above the plain which we have named for convenience ake Dakota.

Date.—From the steep slope of the drift plain of the Coteau des rairies of the upper Big Sioux, we infer the existence of a northern evation before the loess epoch. Quite probably, however, that greater ope is to be referred to a considerable elevation since that time. eing between the Dakota and Minnesota lobes, it would be naturally epressed more than lower latitudes, and when the ice was removed s resilience would be correspondingly energetic.

The generally distinct and continuous slope of the region to the uth, wherever the loess has been deposited, is no more than a fluvio- custrine theory of the loess would explain without perceptible crustal ovement. This northward slope for the most part was quite regular. e have noted the most apparent exception, concerning which we eed add no more at present.

From the perfect horizontality of the general surface within the sec- nd moraine, which, although of lacustrine origin, seems to be contin- ous with the surrounding till, we conclude that the elevation must

[1] Preliminary Report of Explorations in Nebraska and Dakota, 1855-57, pp. 23, 24.

have ceased for southern Dakota by the time the ice had receded to the third moraine; and we have found no evidence that this elevation has continued in any other portion of our field.

AGE OF THE TROUGH OF THE MISSOURI.

In regions north of the field covered by this paper evidence is especially strong that the courses of such streams as the Cheyenne and Grand rivers were formerly eastward to the valley now occupied by the James River. This is derived mainly from the movements of the ice sheet, the traces of old divides, and the narrow character of the trough of the Missouri through this region. For fuller treatment of this topic, see a paper by the writer in the Proceedings of the American Association for the Advancement of Science for 1884.

There is evidence, also, in the region under consideration which indicates that the channel of the Missouri above Niobrara is of recent origin. The White River has a channel rivaling or even surpassing the Missouri in breadth if we consider its broad ancient valley 300 feet above the present one. There is no valley through the Bijou Range of buttes which corresponds to it in size. The Bijou Range itself seems to be an old watershed or remnant of Tertiary rocks which extends between the basins of the White and Niobrara rivers. What the ancient course of the White River was there is not yet evidence of much importance to show, but, remembering the higher level at which it formerly flowed, it may be suggested that a portion of its course remains in the Red Lake channel. Nor is it very difficult to imagine that it once ran along the upper course of American Creek past White Lake.

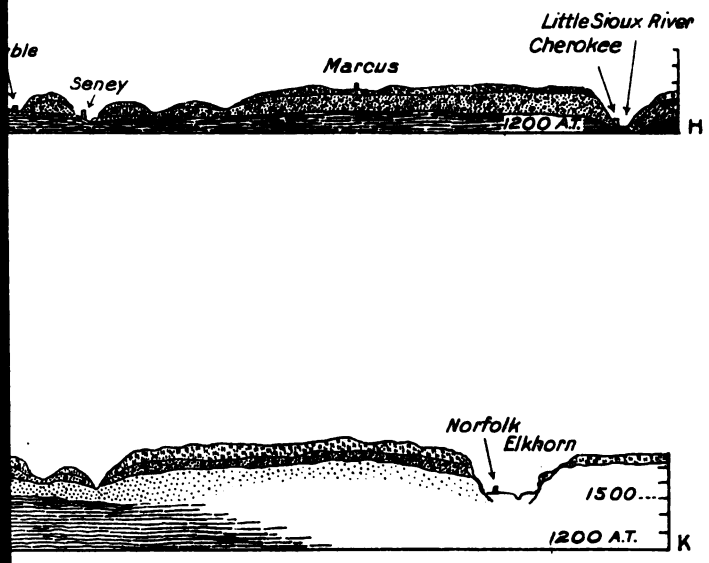
It now remains to consider the age of the Missouri below that point, more particularly that portion bordering the State of Nebraska. Two questions present themselves: 1. Was it pre-Glacial, so far as its location, or was it post-Glacial in origin? 2. If post-Glacial, did it reach its deepest excavation before the loess epoch or in more recent times? If we should find reason for believing it of pre-Glacial origin, the exact date of its location and excavation are not particularly connected with our subject.

IS THE TROUGH OF THE MISSOURI OF PRE-GLACIAL ORIGIN?

We proceed to take up the first of these questions. In favor of the pre-Glacial origin of the trough the following points may be urged:

1. Striæ, supposed to be of Glacial origin, have been found down to the level of the water at Omaha, and very nearly down to that level in southwestern Mills County, Iowa. Not unlikely more careful examination would disclose such striæ at other points.

2. The bed rock lies at a depth of from 50 to 110 feet, or even 125 feet at Omaha, below the present low-water mark; and this leads us to pre-



OLK, NEB.

ALLUVIAL LOESS AND SANDS

LOESS

TILL

MIOCENE

COLORADO CLAYS

DAKOTA FORMATION

SIOUX QUARTZITE

0 5 10 15
SCALE OF MILES

sent in more careful detail the results of examination at five different points, viz: Sioux City, Blair, Omaha, Plattsmouth, and Nebraska City. In the first three cases sections have been kindly furnished the Survey by the engineers of the railroads which cross at these several points. A few notes from engineer Parkhurst, of the Plattsmouth bridge, were received soon after its building. The Nebraska City section has been constructed from notes, taken by the writer in 1880, of an examination carried on by the Corps of United States Engineers, who, to throw light on the history and working of the Missouri, ran a line of borings nearly across the valley at that place. The main facts at these different points may be stated as follows (for a full expression of them we refer to the subjoined cross sections in Pls. XXVI and XXVII):

At Sioux City the river hugs the eastern bank. The rock, judging from that exposed in the bank, is wholly of Dakota sandstone and shales. The river at this point is about 900 feet in breadth and from 5 to 15 feet in depth. The rock lies underneath the present channel of the river on an average from 35 to 80 feet. It lies approximately parallel to the bottom of the water, but near the western bank slopes downward toward the west, and its depth beyond that point has not been determined. These remarks apply particularly to the section near Prospect Hill. The new one, upon which the Pacific Short Line is built, does not differ materially from it. Along the line of the lower bridge, that of the Sioux City and Pacific Railroad, quite different conditions were found. The three deeper borings in the vicinity of the channel, though extending 120 feet below the low-water mark, are reported not to have struck any bed rock. The section is illustrated in Pl. XXVI. When we learn that the Dakota formation is composed mainly of sand, with thin layers of clay, it seems not improbable that its strata may have been mistaken for the loose deposit of the river. In favor of that fact attention is called to the representation of white clay, blue clay, and sand upon the east bank, which would correspond in character with strata of the Dakota. Moreover, upon the west bank, at a depth of 70 feet, is a stratum of clay with its upper surface concave, as though worn by a stream, which also suggests a stratum of the Dakota. Taking the borings as given in the report of the Missouri River Commission for 1890, however, it would appear that river deposits extend to a depth of 120 feet, and how much more has not been determined.

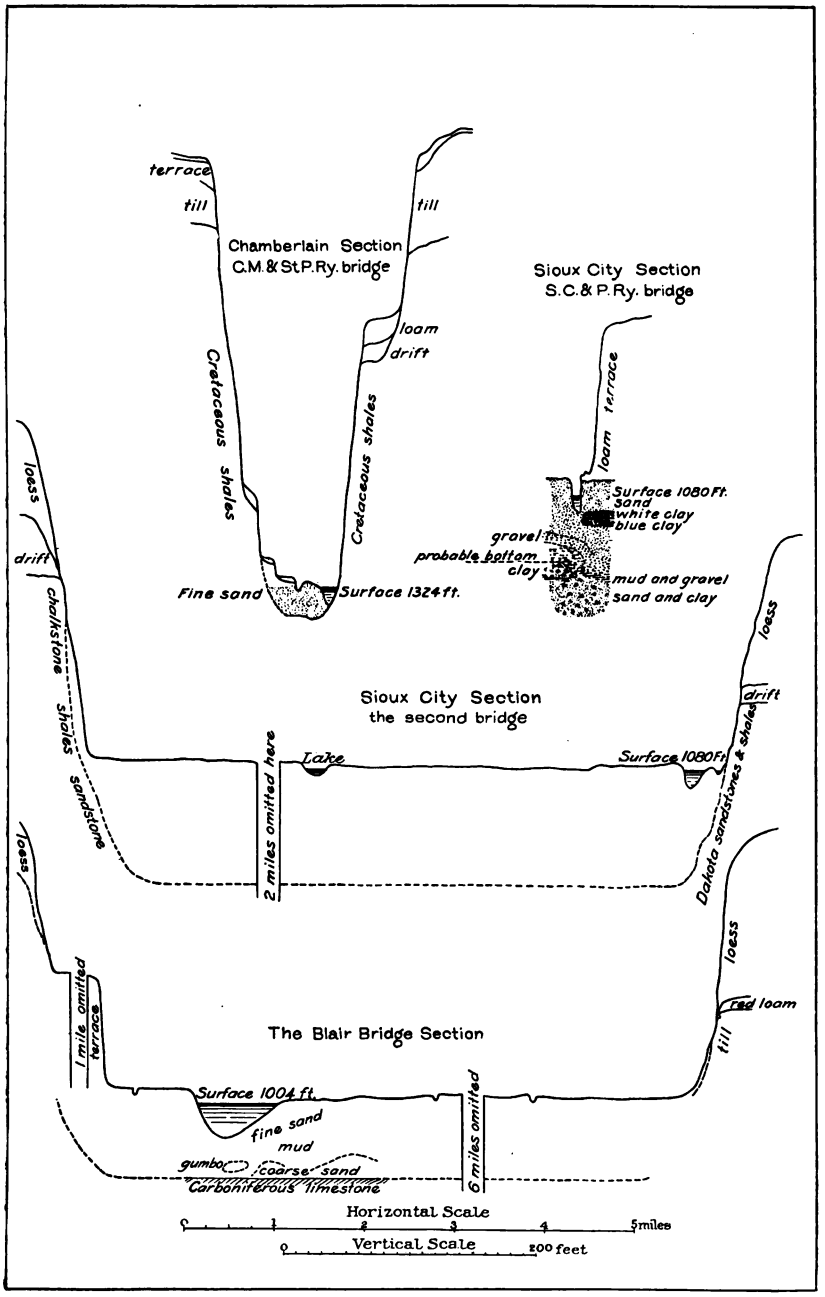
At Blair the river occupies a more central portion of a valley 11 to 12 miles in width. It is three-quarters of a mile east of the high terrace at Blair. The bed rock in the vicinity of the present channel, where the bridge of the Sioux City and Pacific Railroad crosses it, is from 47 to 50 feet below low-water mark. Its surface is quite level in an east-west direction, but seems to dip, or at least to end, abruptly to the north, for a boring 1 mile north of the bridge did not reach rock at a depth of 140 feet. Borings for a mile longitudinally near the bridge, however, indicate a slight decline of surface toward the south.

At the railroad bridge at Omaha the river lies close to the western bank, and, as has been stated before, the rock near by rises above the level of the stream. Underneath the present channel, which at this point is ordinarily about 1,000 feet in width and 2 to 15 feet in depth bed rock lies from 30 to 75 feet below low-water mark. These remarks apply to a section of the Union Pacific Railroad bridge. The section given in our illustration (Pl. XXVII) is that determined by a set of borings crossing the river about half a mile north of the Omaha and Council Bluffs wagon bridge. In this there appears a shelf in the rock bottom on the Omaha side about 20 feet below the surface, or 15 feet below low water. A little east of the river and for three-quarters of a mile farther in that direction the rock lies at a depth of about 80 feet and three borings east of that failed to strike bed rock, though penetrated to a depth of 90 feet. Moreover, the character of the deposit seems to be that of the river, or possibly, in one case, bowlder clay. It is labeled clay and gravel.

At Plattsmouth a much less complete section has been obtained, but the river is close to the western side of the valley and the rock lies from 32 to 54 feet below low-water mark. Moreover, more recent borings have developed the fact that the bottom is quite uneven, and that in some places bed rock lies considerably lower. About a mile and a half farther north borings were carried to a depth of over 85 feet without striking rock.

At Nebraska City the river also lies next the western side of a valley 8 miles in width. The river is about 1,000 feet in breadth, and in places 30 to 40 feet in depth. By the borings before referred to, which were carried on under the directions of Mr. L. E. Cooley, assistant United States engineer, for more than 4 miles, at distances of from 2,500 to 3,000 feet apart, the rock was found to lie at a depth of from 60 to 102 feet below low-water mark. The deepest point found was in the easternmost boring where, according to his statement, "bowlder clay" was struck, suggesting the idea that it may have been the western side of an old channel partially filled with bowlder clay. The average depth of the rock, which on the whole is quite even, may be placed at about 75 feet below low-water mark.

From the Report of the Missouri River Commission for 1890 we learn that north of the bridge about 2 miles borings were carried to a depth of about 170 feet at several points before striking bed rock, and the inference drawn by the engineer was that he had discovered a pre-Glacial channel. He reports that the "principal bed below the general level of the north and south valley of the Missouri is a very tenacious hard, drab-colored clay, mixed with angular fragments of stone, generally of lime," though he reports one of red quartzite, but it is not from this deep channel. He does not doubt that it is till. Assuming that this deep hole is connected with the easternmost boring shown in our figure, he makes the channel run S. 80° E., and suggests that



SECTIONS ACROSS MISSOURI RIVER AT CHAMBERLAIN, SIOUX CITY, AND BLAIR.

may be a portion of an old valley of the Platte. It is difficult to harmonize it with the present Missouri. On the whole, it seems more rational to suppose that the deposit in question is a Carboniferous stratum, and that he has been misled by the interruption or removal of a thin layer of limestone which has, near by, formed the bottom. However, the case should be remembered and further light be sought on the subject.

Now, it appears improbable that the present stream should be still excavating the rock bounding its trough; its depth is too great, it would seem. And yet, at what time since the Glacial epoch is it likely to have reached the bed rock under its channel? On generally received principles we should be inclined, from the depth of the rock, to argue for the pre-Glacial excavation of the trough. Whether this is strongly sustained we shall see presently.

3. The occurrence of till quite low down. At Florence it is found 50 feet thick and more, extending below low-water mark. North of Council Bluffs, near Plattsmouth, and in Mills County, Iowa, typical till is found down to within 30 feet of the level of the river.

In favor of the post-Glacial origin of the immediate valley of the Missouri, it may be argued as follows:

1. A comparison of the course of the Missouri with that of the Mississippi on opposite sides of the State of Iowa brings out the contrast that, while the latter presents rapids of considerable height, nothing of the kind is found along the Missouri. As these rapids have been distinctly traced to changes in the course of the Mississippi during the Glacial epoch, or the want of correspondence of its present channel with that of pre-Glacial times, the absence of rapids in the Missouri would argue in favor of no such divergence, and since we should as easily expect a similar divergence in one case as in the other, if both had pre-Glacial channels, we have some reason for believing that the Missouri had no pre-Glacial channel.

2. Deposits which are evidently of lacustrine and of pre-Glacial origin are found in such close proximity to the present valley as to argue against the idea of a river occupying the trough previous to the deposit of the till. We refer particularly to the section north of Pacific Junction, which has been described on a previous page. This, however, is not conclusive, for we may conceive of small lakes attending a river.

3. Wherever the deposits have been examined in the present trough of the Missouri they have displayed only sand and clay, with no trace of till except in one solitary case, which has been mentioned in the Nebraska City section Pl. XXVII. At Blair and Omaha a few scattered bowlders are found next the rock, but they have evidently been rolled along by the action of the water. At Nebraska City and Omaha clay balls, evidently formed by the caving of clay banks and the rolling of the fragments by the current, occur frequently down to the rock. If the trough were of pre-Glacial age it should be found filled more or less

with bowlder clay. Even if it has been more deeply excavated since th ice age, till should be found occupying a considerable part of the troug

4. The bed rock, wherever it has been exposed, as at Blair and a Omaha, has shown a uniformly waterworn appearance, with no trace of planation or striæ. Though bowlders have been found upon th surface of the rock to the depth of a foot or so, there is no evidence o their corrading the rock as if moved by ice.

We may sum up the evidence from the sections with this result: Th depth of bed rock differs much in the different sections, even wher the localities seem quite uniform. It will be remembered that a borin 1 mile north of Blair bridge is said to have gone 140 feet without strik ing bed rock. When we consider the greatly different kinds of mate rial which the river has excavated it seems likely that the deepness o the channels is the result of softness of the material rather than o great age or the position of an ancient base level. It seems probable tha there would be variations in the depth of the trough of the river sim ilar to those in its width, and the causes for each are probably simila Hence we conclude that the preponderance of evidence is in favor of recent excavation of the lower portions of the channel. At the sam time it should be remembered that we have no complete sections acros the trough and that there is a possibility that an older and deep channel of pre-Glacial age may yet be found.

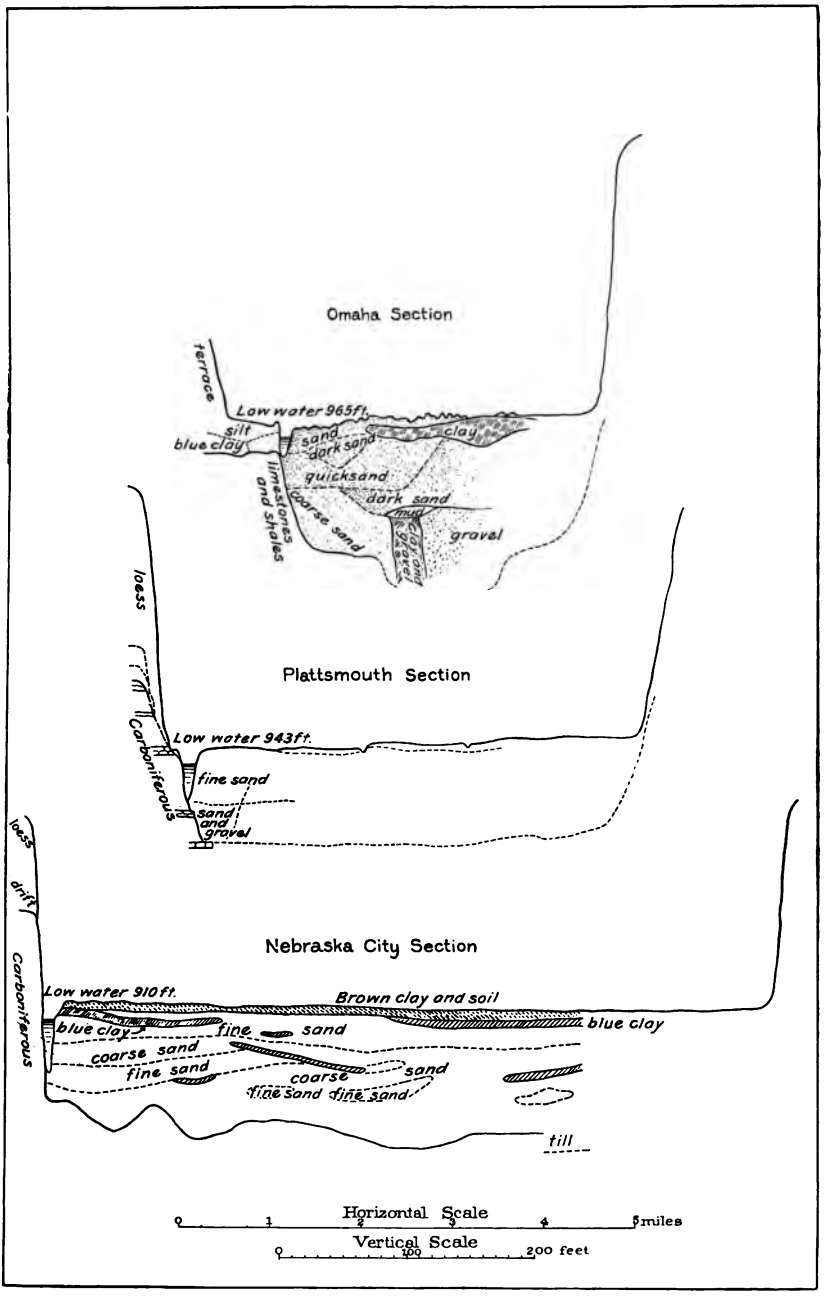
THE TROUGH OF THE MISSOURI STILL DEEPENING.

In support of the view, which may strike some as novel, that th river may cut down to the bed rock at the present time during freshet we have the united testimony of two or three experienced observer Mr. L. E. Cooley, in his report on the improvement of the Missou River at Nebraska City during the year 1879,[1] makes the followi statement:

> The ordinary limit of scour is not the limit when the bank is held, provided t ordinary scour does not extend to permanent strata. The causes which indu heavy cutting will induce heavy scour, provided that cutting is stopped, which w extend to permanent strata if the causes continue sufficiently long. * * *
>
> In many of the borings which have been made here, indurated clay balls, w i vegetable matter, covered with a coating of sand, along with a motley collection gravel stones, are found within a short distance of permanent strata. A precis similar collection containing gumbo balls in a soft state was dredged from 60 f depth at the works. These balls are from cutting banks, and the proof is conc sive that since the river has been running in silt banks, as at present, scour h occasionally, at least, reached permanent strata at 70 to 90 feet depth.

Mr. E. Gerber, assistant engineer of the Fremont, Elkhorn and Mi souri Valley Railroad, who has had direct oversight of the Blair bridg states without qualification that the river at that point cuts down t bed rock twice a year, and he further expresses the opinion that "A many places, especially in sharp bends, where no artificial contractio of the channel takes place, and where there is no greater width tha

[1] Report of U. S. Engineers for 1879–80, Part II, pp. 1066, 1071.



SECTIONS ACROSS MISSOURI RIVER AT OMAHA, PLATTSMOUTH, AND NEBRASKA CITY.

at our bridge, the river scours the bed rock at high water if the rock is not too low." A demonstration of this fact is shown in fig. 31 from soundings taken at the Blair bridge in 1883.

Mr. George A. Lederle, local engineer of the Omaha bridge, expresses a similar opinion, though no definite observations have been made at that point to establish it.

If it be urged that the excavation of so great a valley as is found above Blair and near Nebraska City since the Glacial period is inconceivable, it may be replied that much may be explained by the nature of the formations through which the river has corraded its course.

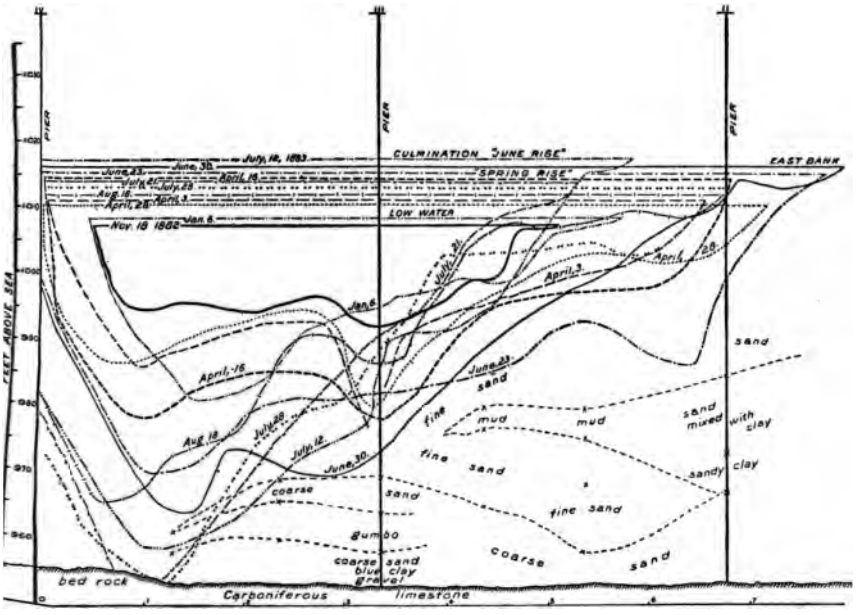


FIG. 31.—Record of soundings at Blair bridge, 1883.

Above Blair the Carboniferous limestone does not appear, and doubtless dips far below the bottom of the river. The great width of the valley above that point has been excavated, therefore, in the loose deposits of the Cretaceous and Tertiary, while its deepening was prevented by the limestone ledge near Blair and De Soto. Even the Carboniferous deposits, though at points largely abounding in limestone, are perhaps one-half clay and very friable sandstone and shale. Moreover, the limestone ledges are rarely more than 10 feet in thickness, and the thickest easily separate into blocks less than 3 feet in diameter. Cliffs of alternating rock and clay may be quite as easily degraded as those of clay alone.

The inequalities of the depth of the bed rock seem to correspond with the character of the strata. For instance, at Blair the shallowness of the trough seems to be referable to a thick stratum which appears above the river at Omaha; the shallowness at Plattsmouth, to

a thick limestone stratum which appears a little above the river a Rock Bluff. The rock thus far dips gently toward the north. Th greater depth at Omaha may be due to the series of clay layers whic intervene between the two, together with the effect of the plunging the current over the limestone stratum as it was worn from the sou toward the north. The great depth at Nebraska City may be similar referred to the rapidity of the stream after passing the limesto stratum at Rock Bluff. Quite possibly, also, this has been increas by a fold which crosses the river at Jones Point, near the mouth of t Weeping Water. The strata dip considerably to the south, perha 100 feet in the distance of a mile. This brings the series of cla which are exposed in the vicinity of Nebraska City down into the riv and accounts for the deeper excavation at that point.

The modus operandi of the excavation of the trough seems to be this wise: While the stream has rapid velocity it preserves much of i straight, narrow, deep channel, which characterizes its upper portion, b when such a channel has attained a uniform slope it begins to for bends which begin the widening of its valley. During this stage th deepest places are in the sharp bends, and only at such points ha the river rock bottom. If it is heavily burdened with sand and silt, a in the case of the Missouri, between such bends, according to th testimony of engineers as well as the common experience of rive captains, the river is very shallow, as the current here is slackene and sand accumulates, especially during high water.

As the river meanders back and forth and the bends continally wor down stream, the whole breadth of the valley becomes scoured out t the depth of the sharpest bends. In this way we may reconcile its pre ent partially filled condition with its recent excavation. The work c broadening the trough does not begin at all points at the same time Where the strata are soft and friable the stream reaches its base-leve of erosion, and expends its energy in widening its valley, while a points where harder strata occur it is spending all its energy in cuttin out its bottom.[1] Thus we may explain, in part at least, the remarkabl widening of the trough of the Missouri between Yankton and Blai and in less degree between Council Bluffs and Rock Bluff, and agai between Jones Point and Peru.

We conclude, therefore, that though the trough may possibly hav been located before the Ice age, its deeper portions must have bee excavated after the deposition of the surrounding till. Moreover, th excavation may have begun soon after the Iowan or even the Kansa stage of the Glacial period.[2]

If it should be asked how we reconcile the arguments in favor of i pre-Glacial origin with the conclusion at which we have arrived, w should simply ascribe the striæ preferably to the action of river ic though they may have been caused by land ice of an older epoch, a

[1] Cf. Powell's Exploration of the Colorado River, p. 202 et seq.
[2] Cf. Todd, New lights on the drifts: Proc. Iowa Acad. Sci., 1898.

the deposition of till at altitudes near the river *where it is not the* result of landslides to depressions in the surface on which the *till* was deposited, for the general surface of the Carboniferous strata seems to have been far from even. The deep deposits of sand and gravel in the vicinity of Council Bluffs and Omaha we should ascribe to similar cause. It would seem that when the Missouri began its course during or after the drift period, and in crossing some of these deep holes large quantities of this material collected in them.

The very rough surface of the Carboniferous rocks is graphically described by Dr. F. V. Hayden in his Final Report on Nebraska, p. 25. Speaking of eastern Nebraska, he says: "If we can imagine the superficial material entirely removed from the country, the surface, as it seems to me, would be rugged in the extreme. * * * The massive piles of limestone would stand around here and there scattered over the surface like gigantic ruins." This quotation, while expressing a truth, may be misunderstood. If we should remove the pre-Glacial clays and sand beds the buttes of Carboniferous limestone would probably rise less than 200 feet above the intervening valleys.

If this conclusion be correct, there may not have been very great erosion of the older rocks since the Ice age.

WAS THE TROUGH EXCAVATED PREVIOUS TO THE LOESS EPOCH?

This depends largely upon the theory one may hold concerning the origin of the loess. If it is looked upon as eolian, the two may have been developing simultaneously. In that case the conception would be that the Missouri began its course after the Kansan epoch, and that the material of the loess must have been derived from its bars and banks during its lower stages and spread over the uneven surface adjacent. But if we look upon it as of a lacustrine or a fluvio-lacustrine origin, it would seem necessary to conceive the trough of the Missouri to have been subsequent. If we favor the latter views, the base-level of erosion and deposition must have been approximately coincident with the present upland level of the loess region. We may have some fragments of the original surface still extant in the "flats" which we have already mentioned as occurring in western Iowa, Nebraska, and Missouri. Accordingly, the most of the upland loess was deposited no later than the Iowan epoch. If it seems incredible that this trough, which really is of vast extent, has been excavated since that time, we may find it more credible by considering the following points:

1. The present trough may have been largely excavated from Pleistocene deposits. We have already alluded to the very uneven surface of the older rocks. If the drift were resting upon deep sand beds, as has been found in northern Nebraska, this would assist largely in the removal of the material.

2. The Missouri during the Wisconsin epoch was the main channel for carrying off the water from the whole western edge of the great ice sheet. Estimates will be found more fully given in the Report of the

Missouri Geological Survey, Vol. X, p. 202. According to these, the probable average size of the stream was about ten times greater than at present. This would add greatly to its eroding power.

3. The loess has a peculiar property for creeping and rearranging itself at lower levels. This subject will be found more fully treated in the Proceedings of the Iowa Academy of Sciences for 1897. We simply call attention here to the following facts: The loess upon steep slopes frequently shows a step-like surface. Most generally it attracts little attention, and has been referred by some to the checking by vegetation along steep hillsides or to the tramping of grazing animals. Even in this moderate degree deep excavations will show that these steps are caused by a series of slight faults running transverse to the direction of the slopes. They may be compared to crevasses of glaciers. It appears that this phenomenon occurs when moisture has accumulated in the base of the formation and dissolved the cementing material of the loess and rendered it plastic, or the moisture may be in the underlying clay or sand, rendering it similarly plastic. Occasionally this phenomenon becomes so marked that the crevasses or faults have a throw of several inches. During rain or the spring thaws these cracks are filled and recemented. Similar results are also accomplished by hillside wash, which frequently becomes very marked upon steep slopes. After prolonged rains the formation becomes saturated and is very easily washed away and rearranged. Because of its straticulate structure and homogeneous color and composition it is very difficult for anyone to distinguish the newly arranged material from the original deposits. In this way we may find a rational explanation of the recent origin of the troughs of the Missouri and its tributary streams, and also in considerable degree of the uneven surface and great vertical range of both the loess and the drift.

ELEVATIONS.

Elevation above sea level of stations on Fremont, Elkhorn and Missouri Valley Railroad west of Norfolk Junction.

[Furnished by the kindness of E. Gerber, assistant engineer.]

Main line:	Feet.	Main line—Continued:	Feet.
Battle Creek	1,606	Ainsworth	2,538
Burnett	1,695	Johnstown	2,618
Oakdale	1,726	Wood Lake	2,704
Neligh	1,761	Arabia	2,735
Clearwater	1,808	Thatcher	2,669
Ewing	1,875	Valentine	2,598
Inman	1,946	Creighton Branch:	
O'Neill	1,992	Norfolk (town)[1]	1,542
Emmet	2,039	Hadar	1,574
Atkinson	2,125	Pierce	1,599
Stuart	2,171	Morehouse	1,657
Newport	2,249	Plainview	1,700
Bassett	2,340	Creighton	1,617
Long Pine	2,416		

[1] This is 1 mile from the junction, which is 1,532 feet.

Elevations on the Chicago, *St. Paul, Minneapolis and Omaha Railway.*

[Furnished by the kindness of C. W. Johnson, chief engineer.]

Locality.	Distance.	Altitude.
Main line:	*Miles.*	*Feet.*
Sioux City, crossing of Second and Howard streets	.....	1,122.2
Missouri River	.....	1,102.33
Covington	0	1,124
Dakota City	5	1,121
Coburn Junction	10	1,124
Do	12	1,125
Hubbard	14	1,161
Grade over Pigeon Creek	20.5	1,356
Bottom of Pigeon Creek	20.5	1,307
Simons Siding (summit)	22	1,436
Grade of Elk Creek	23.5	1,356
Bottom of Elk Creek	23.5	1,336
Do	23.6	1,352
Summit	26.2	1,494
Emerson Junction	27.2	1,450
Flourney	34.5	1,399
Pender	39	1,347
Bancroft	48.7	1,316
Lyons	56.3	1,306
Oakland	65	1,300.3
Craig	70	1,280
Summit	71.5	1,341
Tekamah	79	1,075
Herman	86.2	1,050
Hiland	91.2	1,031
Blair	96.2	1,100
Mills	101.5	1,026
Calhoun	105.2	1,094
Summit	116	1,232
Florence	120	1,033
Omaha	126.2	1,065
Ponca Branch:		
Coburn Junction	0	1,124
Jackson	3	1,141
Grade at Elk Creek	4.2	1,156
Bottom of Elk Creek	4.2	1,140
Grade at Elk Creek	6	1,174
Bottom of Elk Creek	6	1,152
Summit	11	1,279
Grade at Badger Creek	11.5	1,243
Bottom of Badger Creek	11.5	1,225
Ponca	16	1,162

Elevations on the Chicago, St. Paul, Minneapolis and Omaha Railway—Continued

Locality.	Distance.	Altitude.
Norfolk Branch:	*Miles.*	*Feet.*
Emerson	0	1,450
Summit	2.5	1,541
Wakefield	9.5	1,404
Wayne	18.6	1,469
Grade at South Logan Creek	19.2	1,470
Bottom of South Logan Creek	19.2	1,452
Northside	31.3	1,643
Summit	34.2	1,809
Hoskins	38	1,684
Norfolk	46.5	1,542
Hartington Branch:		
Wakefield	0	1,404
Grade at Logan Creek	3.7	1,422
Bottom of Logan Creek	3.7	1,404
Concord	10	1,455
Grade at Logan Creek	17.5	1,503
Bottom of Logan Creek	17.5	1,490
Coleridge	24	1,672
Hartington	33.8	1,404.5
Sioux Falls Branch:		
Junction	181.8	1,633
Summit, grade	184.5	1,691
Little Rock River—		
Water	187.4	1,629
Bridge	187.4	1,649
Rushmore	190.1	1,665
Adrian	196.9	1,538
Kanaranza Creek—		
Water	198	1,499
Bridge	198	1,511
Summit, grade	199.5	1,569
Drake	203.7	1,516
Elk Slough, grade	206.2	1,469
Summit, grade	207.1	1,515
Rock River, water	210.3	1,423
Luverne	211.1	1,451
Summit, grade	216.1	1,543
Beaver Creek—		
Station	219.3	1,443
Water	219.8	1,385
State Line	224.4	1,383
Valley Springs	225.2	1,392

Elevations on the Chicago, St. Paul, *Minneapolis and Omaha Railway—Continued.*

Locality.	Distance.	Altitude.
Sioux Falls Branch—Continued.	*Miles.*	*Feet.*
Big Sioux River { low and high water	232.4	1,281 / 1,302
Big Sioux River { bridge	232.4	1,307
Terrace south of river	234.4	1,363
Sioux Falls	240.2	1,394
Big Sioux River, high and low water	240.4	1,381 / 1,385
Summit, grade	241.6	1,471
Big Sioux River, water	243.4	1,403
Skunk Creek—		
Water, sec. 31, T. 102, R. 50	250	1,449
Bridge	250	1,465
Hartford Siding, sec. 22, T. 102, R. 51	254.4	1,561
Summit, grade, sec. 9, T. 102, R. 52	261.2	1,692
East Vermilion River—		
Water, sec. 27, T. 103, R. 53	268	1,455
Bridge	268	1,469
Montrose Siding, close west of last	268.3	1,471
West branch of East Vermilion—		
Water, southwest corner of sec. 15, T. 103, R. 53	269.5	1,468
Bridge here	269.5	1,480
Summit, grade	275.9	1,586
Salem, sec. 13, T. 103, R. 55	279.5	1,517
West Vermilion River, water, sec. 15, T. 103, R. 55	281	1,457
Wolf Creek, water, sec. 20, T. 104, R. 56	290.6	1,370
Fawn Lake, water, T. 105, R. 58	303.5	1,320
Stony Creek, water, sec. 25, T. 106, R. 60	313	1,253
James River, water, sec. 12, T. 106, R. 61	320.2	1,212
Prairie, 5 miles west of last	325	1,276

Elevations along the Dakota Central Division of the Chicago and Northwestern Railw from Hawarden, Iowa, to Iroquois, South Dakota.

Locality.	Station.	Altitude.
		Feet.
Hawarden	0	.....
Crossing, Chicago, Milwaukee and St. Paul—		
Grade	18	1,182
Ground	18	1,179
East bank Big Sioux	38	1,182
Do	108	1,181
Do	378	1,437
Alcester	468	1,355
Do	521	1,320
Do	538	1,344
East bank Brule Creek	584	1,310
Do	748	1,345
Do	908	1,513
Beresford	928	1,505
Do	1,118	1,340
Do	1,358	1,240
Centreville	1,463	1,233
East bank Vermilion	1,487	1,223
Do	1,528	1,207
Do	1,538	1,240
Do	1,953	1,325
Hurley	2,154	1,272
Do.	2,568	1,360
Crossing of Chicago, Milwaukee and St. Paul	2,579	1,335
Grade of Chicago, Milwaukee and St. Paul	2,579	1,330
Grade of Chicago and Northwestern	2,579	1,335
Parker	2,627	1,340
East bank of West Vermilion	2,637	1,340
Do	2,837	1,506
Do	3,027	1,500
Do	3,337	1,560
Canistoga	3,487	1,555
Salem and crossing of St. Paul, Minneapolis and Omaha	4,017	1,515
East bank of West Vermilion	4,182	1,485
Do	4,277	1,530
Canova	4,662	1,525
Vilas	5,187	1,480
East bank of Rock Creek	5,510	1,426
Do	5,657	1,466
Carthage	5,857	1,440
East bank Redstone Creek	5,865	1,436
Esmond	6,227	1,430
Do	6,397	1,450
Do	6,617	1,425
Iroquois	6,672	1,400

Elevations along a preliminary survey *from Chamberlain, South Dakota, to Lemars, Iowa.*

[Furnished by B. B. Colborne, who made it in the interests of the Chicago, Milwaukee and St. Paul Railway. Datum, 300 feet below starting point, which happened to be the bottom (not bottom land) of the Big Sioux River.]

Locality.	Station.	Elevation above datum.
		Feet.
One mile north of Chamberlain, South Dakota, water in Missouri River above sea 1,321 feet	.....	221.95
Chamberlain, station	.....	251
One mile east of Chamberlain	0	300
Summit, sec. 34, T. 104, R. 70	400	505.7
East end of Red Lake	500	450
Water in lake	500	440
Bijou Hills Gap	1,300	649.8
Pratt Creek, water, sec. 2, T. 99, R. 68	2,850	358.4
Do	0	358.4
Sec. 33, T. 99, R. 68	300	492
Summit	500	522.9
Pease Creek, sec. 32, T. 98, R. 66	859	395
Summit	1,150	463
West end of Lake Andes	1,400	330
Lake Andes, water	1,400	319.6
Channel southwest from lake	1,450	326
Between moraine and lake	1,500	342
Choteau Creek:		
Bottom, sec. 29, T. 96, R. 63	2,000	280
Sec. 25, T. 94, R. 62, grade	3,000	184
Sec. 36, T. 94, R. 62, grade	3,050 ?	181
Sec. 36, T. 94, R. 62, water	0	169
Summit	300	327
Emanuel Creek:		
Quarter of a mile above Springfield station	600	123
Three-quarters of a mile below Springfield station	.....	104
Near station	.....	98
Water in Missouri River at—		
Springfield	.....	76
Yankton	.....	48
Yankton, grade of Chicago, Milwaukee and St. Paul	.....	64
Edge of river bottom at mouth of Turkey Creek, sec. 13, T. 94, R. 54; station from Springfield	2,200	58
Summit	2,500	227
West edge of Vermilion, second bottom	2,750	110

Elevations along a preliminary survey from Chamberlain, South Dakota, to Lemars, Iowa—Continued.

Locality.	Station.	Elevation. above datum.
		Feet.
Vermilion River:		
Grade, sec. 23, T. 94, R. 52 (Bloomingdale)	2,950	32
Lower bottom, east edge	3,500	38
Second bottom, west edge	3,150	102
Second bottom, east edge	3,500	148
Brule Creek:		
Sec. 16, T. 94, R. 50 (Emmett)	3,550	105
Water	.....	95
Brule Creek, bottom	3,700	125
Summit	3,850	268
Big Sioux:		
Bottom	4,050	27
River	4,100	0
Railroad crossing at Akron	.....	28
Summit	4,500	277
Broken Kettle Creek, sec. 8, T. 92, R. 47	4,650	158
Summit, sec. 36, T. 92, R. 47	4,850	280 301
Mink Creek	5,100	105
Mink Creek, water	5,100	87
Sec. 23, T. 92, R. 46	5,150	8.6
West Floyd River:		
Grade	5,200	79
Water	.....	60
Floyd River:		
Grade	5,300	84
Water	.....	60
Lemars, 5–10 feet lower than Illinois Central station	5,400	95

Elevations on survey north of Lake Andes, from sec. 28, T. 96, R. 63, to Platte Creek Crossing, sec. 2, T. 99, R. 63.

Locality.	Station.	Elevation.
		Feet.
Crossing of Lake Andes, sec. 16, T. 97 R. 64, (water 7 feet deep)	0	319.6
Summit north of Lake Andes	500	564.9
Pease Creek	800	487
Summit	1,150	548
Platte Creek	1,450	358

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office.

[Furnished by the courtesy of D. J. Whittemore, chief engineer.]

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
	Feet.	*Feet.*
Sheldon, Iowa	822	1,404
Boyden, Iowa	830	1,412
Patterson, Iowa	842	1,424
Summit west of Patterson	869	1,451
Rock Valley	662	1,244
Junction of Rock Valley	658	1,240
Rock River:		
Track	657	1,239
Water	635	1,217
Inwood	880	1,460
Sioux River:		
Track	657	1,239
Water	635	1,217
Canton	655	1,247
Crossing at Canton Junction	670	1,252
Worthing	772	1,354
Lennox	763	1,345
Vermilion River (bridge)	711	1,293
Chicago and Northwestern Railway, crossing east of Parker	736	1,318
Parker	758	1,340
Summit west of Parker	894	1,476
Junction at Marion Junction	856	1,438
Station at Marion Junction	858	1,440
Wolf Creek bridge	830	1,412
Bridgewater	829	1,411
Emery Station	797	1,379
Pierre Creek bridge	720	1,302
Alexandria	761	1,343
James River bridge east of Mitchell:		
Track	629	.....
Water	615	1,197
Station at Mitchell	710	1,292
Junction west of Mitchell	706	1,288
Mount Vernon	822	1,404
Plankinton	937	1,519
White Lake	1,055	1,637
Kimball	1,197	1,779
Pukwana	955	1,537

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office—Continued.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
	Feet.	*Feet.*
Chamberlain	772	1,354
Missouri River at Chamberlain	739	1,321
Running Water Branch:		
Marion Junction	856	1,438
Freeman	920	1,502
Menno	733	1,315
Station, James River	602	1,184
Bridge over James River—		
Track	598	1,180
Water	587	1,169
Scotland	756	1,338
Tyndall	827	1,409
Springfield	643	1,225
Running Water	629	1,211
Water in river	.....	1,221
Sioux City and Dakota Division:		
Junction near Scotland	772	1,354
Lesterville	793	1,375
Utica	797	1,379
Yankton (Burleigh street)	602	1,184
Bridge over James River—		
Track	586	1,168
Water	570	1,152
Gayville	576	1,158
Meckling	565	1,147
Bridge, Vermilion River—		
Track	559	1,141
Water	538	1,110
Vermilion	559	1,141
Burbank	551	1,133
Elk Point	540	1,122
Jefferson	527	1,109
McCook	521	1,103
Bridge, Sioux River—		
Track	521	1,103
Low water	497	1,079
Sioux City	513	1,095

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office—Continued.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Elk Point to Sioux Falls Junction:	*Feet.*	*Feet.*
Elk Point	540	1,122
Bridge, Sioux River—		
Track	521	1,103
Water	507	1,089
Westfield	540	1,122
Akron (Portlandville)	564	1,146
Chicago and Northwestern crossing (Hawarden)	587	1,169
Calliope	591	1,173
Bridge, Sioux River—		
Track	598	1,180
Water	571	1,153
Eden	631	1,213
Austen	613	1,195
Fairview	623	1,205
Beloit	649	1,221
Bridge, Sioux River—		
Track	648	1,230
Water	633	1,215
Crossing at Canton Junction	670	1,252
Bridge, Sioux River at Sioux Falls—		
Track	804	1,486
Water	787	1,369
Sioux Falls	802	1,384
Bridge over Sioux River at Dell Rapids—		
Track	907	1,480
Water	879	1,451
Station, Dell Rapids	901	1,483
Bridge, Sioux River—		
Track	909	1,491
Water	894	1,476
Track	928	1,510
Water	911	1,493
Sioux Falls Junction	929	1,511
Southern Minnesota Division:		
Airlie, Minnesota	1,070	1,652
Flandreau	983	1,565
Bridge, Sioux River—		
Track	938	1,520
Water	928	1,510

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iow as per profiles in chief engineer's office—Continued.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Southern Minnesota Division—Continued.	*Feet.*	*Feet.*
Egan	943	1,525
Sioux Falls Junction	929	1,511
Coleman, Dakota	1,109	1,691
Wentworth	1,108	1,690
Madison	1,081	1,663
Bridge, East Vermilion River—		
Track	1,067	1,649
Water	1,040	1,622
Winfred	1,122	1,704
Howard	980	1,562
Chicago and Northwestern crossing, Vilas	888	1,470
Roswell	814	1,396
Diana (Artesian)	727	1,309
Bridge, James River—		
Track	652	1,234
Water	627	1,209
Forestburg	644	1,226
Woonsocket	720	1,302
Hastings and Dakota Division:		
At lower station at Ortonville	402	984
Bridge, Minnesota River—		
Track	383	965
Water	370	952
Station, Milbank Junction	559	1,141
Summit siding (summit of Coteaus)	1,415	1,997
Waubay	1,225	1,807
Webster	1,258	1,830
Bristol	1,190	1,772
Andover	891	1,473
Groton	719	1,301
Bridge, James River—		
Track	696	1,278
Water	684	1,266
Bath	715	1,297
Chicago and Northwestern crossing	714	1,296
Aberdeen	715	1,297
Mina	847	1,429
Ipswich	945	1,527

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office—Continued.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Whetstone Branch:	*Feet.*	*Feet.*
Milbank Junction	559	1,141
Corona	584	1,166
Wilmot	606	1,188
End of track (33 miles from Milbank)	637	1,219
James Valley line:		
Mitchell		
Junction near Mitchell	706	1,288
Letcher	713	1,295
Woonsocket	720	1,302
Alpena	731	1,213
Virgil	755	1,337
Wolsey	765	1,347
Chicago and Northwestern crossing (Wolsey)	764	1,346
Bonilla	750	1,332
Tulare	729	1,311
Redfield	705	1,287
Chicago and Northwestern crossing	706	1,288
Ashton	708	1,290
Mellette	792	1,294
Warner	793	1,295
Chicago and Northwestern Railway crossing	712	1,294
Aberdeen	715	1,297
Westport	745	1,227
Frederick	783	1,365
Ellendale	864	1,446

NOTE.—In preparing the above statement the elevations above Lake Michigan were determined by reducing the datum lines of the various profiles on file in the office to lake level, beginning at Milwaukee, thence to La Crosse, and thence by four different routes to a common point in Dakota, where it was found that the extreme variation was not more than 5 feet. The elevations given are about an average of the extremes found.—E. O. Reeder, assistant engineer.

Supplementary list.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Scotland and Armour line:	*Feet.*	*Feet.*
Scotland	756	1,338
Tripp	974	1,556
Delmont	899	1,481
Armour	932	1,514
Tripp and Mitchell line.		
Tripp	974	1,556
Parkston	811	1,393
Ethan	756	1,338
Mitchell	712	1,294

Elevations along the Sioux City, O'Neill and Western Railway.

[Obtained through the kindness of J. H. Charles, of Sioux City, from F. C. Hills, receiver.]

Locality.	Elevation above datum.	Elevation above sea.
	Feet.	*Feet.*
Government bench mark, Sioux City	106.69	1,111.8
South Sioux City, Nebraska	100	1,106
Jackson	110	1,116
Siding, sec. 25, T. 29, R. 6. E	175	1,181
Waterbury	280	1,286
Summit east of Allen	515	1,521
Allen	480	1,486
Summit east of Dixon	550	1,556
Dixon	445	1,451
Laurel	465	1,471
Belden	540	1,546
Logan Creek, bridge	600	1,606
Randolph	660	1,666
Summit west of Randolph	825	1,831
Osmond	655	1,661
Bridge east of Plainview	640	1,640
Plainview	668	1,674
Brunswick	846	1,852
Savage	860	1,866
Orchard	920	1,926
Emporia	965	1,971
Page	947	1,953
O'Neill	965	1,971

Elevations along the Sioux City, *O'Neill and Western Railway—Continued.*

Locality.	Elevation above datum.	Elevation above sea.
	Feet.	*Feet.*
Western line of Hall County		2,338
Western line of Rock County		2,576
Western line of Brown County		2,763
Crossing, Middleloup, Cherry County, water level		2,932
Highest point, R. 33, Cherry County, three-fourths mile east of west line		3,379
Highest point, R. 37, Cherry County, one-half mile east of west line		3,658
Western margin of Cherry County		3,837
Highest point, R. 44, Sheridan County, west line		3,945
Crossing, Box Butte Creek, Sheridan County, western margin		3,845

Elevation of the Sioux City and Northern Railroad.

[Through the kindness of S. J. Beals, receiver.]

Locality.	Elevation above sea.
	Feet.
Sioux City, shops east of Division street	1,109.6
Dalton, Iowa	1,212.5
Struble, Iowa	1,271.7
Garretson, South Dakota	1,496.1

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LETTER OF TRANSMITTAL.

AMHERST COLLEGE,
Amherst, Mass., July 6, 1898.

SIR: The accompanying work is presented for publication as a bulletin of the United States Geological Survey. It is supplementary to the text of the Housatonic folio of the Geologic Atlas of the United States, and should be used in connection with the maps and sections of the folio.

Very respectfully, your obedient servant,

B. K. EMERSON.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE GEOLOGY OF EASTERN BERKSHIRE COUNTY, MASSACHUSETTS.

By B. K. EMERSON.

INTRODUCTION.

The country here described is represented on the Becket and Sandisfield sheets, and in Bear[1] Mountain extends into the area of the Sheffield sheet, of the topographical map of the State of Massachusetts. On the east it adjoins the territory discussed by the author in a recent monograph of the United States Geological Survey.[2] On the north it is bounded by the Hoosac Mountain area, which has formed the subject of a monograph by Professors Pumpelly and Wolff.[3] It is a section across the Green Mountain chain in Massachusetts, a deeply eroded region of pure Appalachian type, composed of sharply folded pre-Cambrian and Paleozoic crystallines.

This territory forms part of a deeply trenched plateau, and along the western border of the area the ground sinks by a steep scarp to the low limestone valley of the Housatonic. Upon the upland the surface is underlain by a series of pre-Cambrian anticlines, more or less overturned to the west, which form an almost continuous band across the State. They are included in a much broader band of Cambrian conglomerate-gneisses. The Cambrian quartzite and the Stockbridge limestone rise somewhat onto the upland from the west, and the Cambrian gneisses dip steeply beneath newer sericite-schists along the east border of the area.

The axes of the folds strike mainly north and south, but in the western-central part of the tract they bend in great curves to the west, even into sickle shape, and in extreme form are overturned and at the same time bent in curves, producing a complex, fan-like structure.

[1] The United States Board on Geographic Names has decided that the name used for this mountain in the publications of the United States Government shall be Bear, and not Beartown. The author of this bulletin states that there are other "Bear" mountains, and that this mountain will always be known in the region as Beartown Mountain.—EDITOR.

[2] The geology of Old Hampshire County, Massachusetts, by B. K. Emerson: Mon. U. S. Geol. Survey, Vol. XXIX.

[3] The geology of the Green Mountains in Massachusetts, by R. Pumpelly, J. E. Wolff, T. Nelson Dale: Mon. U. S. Geol. Survey, Vol. XXIII.

TOPOGRAPHY.

The region under discussion preserves distinctly the form of a plateau. A most striking topographical feature of this plateau is its rapid sinking on the west to a limestone plain 1,000 feet above sea level. Where the limestone penetrates far east into the crystalline area, in Dalton, East Lee, and Tyringham, it is sunk to the same low level as in the open valley to the west, and that this is due to the solubility of the limestone is suggested by the fact that the Cheshire quartzite, much more exposed and softer, is preserved across the central part of Washington fully as far to the east and at a much higher level.

A low crest line runs N. 10° W. through Peru, in the northeast corner of the area considered, rising to 2,295 feet 2 miles south of the center of the town and continuing north as the crest line of Hoosac Mountain (Spruce Hill, 2,480 feet). From this crest line the plateau sinks slightly westward to where its bluffs look down on the Housatonic Valley, with the highest peaks rising from 1,740 feet in the northern part of the area to 2,075 feet in the central part.

In the southern half of the area the bluff which has formed the western edge of the plateau clear across the State extends westerly in Bear Mountain (1,865 feet), facing northward for several miles, and is then lower and less pronounced across the southern half of the area, sinking to 1,750 feet across New Marlboro.

Also in the southern half of the area another broad crest, replacing the first, rises on the west side of the plateau, reaches 2,120 feet in Becket Mountain, and broadens to the south across Tyringham and New Marlboro. These crests sink gradually toward the south. A broad but slight depression, occupied by many ponds, crosses the area between the crests, from Hinsdale to the Otis reservoir.

There is also a southeastward sinking of the level from the second crest line to 1,450 feet at the southeast corner of the area, so that the plateau dips west in its northern half and east in its southern half.

The watershed follows the first crest for several miles, then crosses the depression transversely to the west, and continues down the western crest. This throws most of the drainage into the Connecticut River, though the watershed makes a wide detour to the east around the headwaters of the Housatonic.

This watershed crosses three well-marked wind gaps or valleys, which are not occupied by any water course but from which tributaries of the Housatonic flow northwest and those of the Connecticut southeast. These are (1) the deep canyon between Washington Station and Becket, occupied by the Boston and Albany Railroad; (2) the prolongation of the East Lee Valley at Greenwater Pond; and (3) the less marked upland prolongation of the low Tyringham Valley which connects with the Clam River Valley. These wind gaps form the centers of the three important transverse features of the topography. The deep limestone bay of Dalton is continued in the pre-Cambrian basin of Hinsdale at a higher

level, and this narrows into the Becket Canyon, which is continued in the Westfield River Valley across the whole range. Thus is formed the only passageway for a railroad across the range.

The Dalton limestone bay was caused by the removal of the Stockbridge limestone, which here penetrates far into the mountain mass. East of this bay the greater solubility and consequent erosion of the gneisses and limestones of the overturned pre-Cambrian anticline has caused the broad Hinsdale depression where the anticline is wide; and the same anticline narrows and becomes vertical where it bends southeastward, making the deep canyon which extends from Washington Station to North Becket.

The divide is now at Washington Station, and the Housatonic, coming down from the Washington Hills, flows north across the low depressions here mentioned and swings around to the south, following the larger limestone valley; the Westfield River flows south through the canyon and then southeast until it joins the Connecticut.

From Becket eastward the position of the Westfield is normal, depending on the original southeast slope of the plateau and disregarding the geological structure, except that it seems somewhat influenced by faults. Above this point the structure has controlled the course of the stream from Washington to Becket and forced it into the canyon; and the drainage also seems to have been inverted, that from Dalton, Windsor, and Hinsdale, which formerly went into the Westfield River at Washington, being now carried westward by the Housatonic. If the course of the Housatonic from Dalton south be inverted, nearly all the tributaries on the west would then flow southeast in normal relation to it. A similar statement is true of several of those on the east in so far as they have not come under the influence of the limestone, which has by its solution produced long ponds and deflected several streams into them. Indeed, each lobe of the pre-Cambrian has become the bed of a brook.

The present course of the Housatonic across Hinsdale is complicated by the extensive glacial lake deposits in that town. When the ice had just shrunk away from the uplands and still filled Pittsfield Valley and the Dalton bay, the valley of the Westfield became a main outlet for the glacial waters, which widened above Becket Canyon into a lake across the low ground of Hinsdale and Washington, producing the broad sand flats that extend across this area and the great delta flat which rises just east of Hinsdale station and extends to the Center. Its lobed southward-facing front, swinging in a great loop between these two places, is well marked on the map. The extremely sinuous course of the Housatonic is due to its passage, with slight fall, across these fine sands.

The notch across the mountains seen in the East Lee-Farmington River Valley is formed in a similar way. The Stockbridge limestones project but little into the East Lee Valley of pre-Cambrian limestones, but this valley is prolonged into the Farmington River Valley, which

cuts clear across the range. In its lower third, from New Boston south, the stream runs in a narrow gorge cut by itself without regard to the substructure and controlled by the old surface of the base-level plain over which it began its flow. The middle third is controlled in some degree by the Otis fault (see map, Pl. IX). The northwestern third is controlled similarly to the Hinsdale area, by the solution and erosion of the limestone and the formation of the deep East Lee Valley along the long and narrow anticline which sweeps in a broad curve from East Lee to West Becket.

South of the southern end of Greenwater Pond there is a low divide in the deep valley bottom. South of this point the waters flow into the Farmington River; north of it they flow, by Greenwater Pond Brook, into the Housatonic. This brook seems also to indicate a reversed drainage, as the tributaries make obtuse angles with the main brook and seem to have once been tributary to a southeast stream.

The Dalton phase is lacking here, as the Stockbridge limestone does not penetrate the crystallines.

The great Lenox fault at the foot of the mountains cuts across the mouth of the valley and gives access to it by dropping the western half of the Tyringham pre-Cambrian below the bottom of the Housatonic Valley.

In the Tyringham Valley, next south, the limestones once penetrated far southwest along the Tyringham fault, but have now been mostly cleared out from the deep, narrow valley, which is abruptly closed at its lower end but continues at a much higher level to connect with the transverse valley of Clam River, which joins the Farmington River at New Boston.

One can dimly discern in the Tyringham Valley a fragment of pre-Cambrian topography and its explanation. In the Hop Brook gorge, at the head of the valley, the pre-Cambrian limestones appear as the core of an anticline, which ends, with sharp southeastern pitch, near the mouth of Hayes Pond. This anticline extends along the axis of the valley beneath the Cambrian and appears in its middle at the Brookside mill below the "Cobble," and its erosion in pre-Cambrian times can be said, with considerable probability, to have formed a long, narrow bay, into which the progressive transgression of the Cambrian sea brought first the sand beds of Cambrian times and then the deep-water calcareous deposits which formed the Stockbridge marbles that once filled the valley. The steep southern pitch of the limestone core of the anticline at its south end caused the abrupt termination of the valley in that direction.

In a similar way a curious topographical feature was formed in the basin of Goose Pond. A long, narrow, curved anticline brought the limestone to a level where it could be reached by solution and erosion, and this deep linear depression is the result.

In Monterey the limestones extend again far eastward, and their *solution has* produced a broad upland valley and a westerly drainage

whose limits are quite closely coincident with the former area of limestone.

Finally, in the southern portion of the area there are many small ponds occupying pre-Cambrian limestone areas and surrounded by Cambrian gneisses, where I suspect that the solution of the limestone has caused the caving in of the gneisses, and that their final removal by the ice has produced these small and peculiar land-locked ponds.

HISTORICAL SKETCH OF THE BUILDING OF THE PLATEAU.

The country is now a central section of a deeply eroded mountain region of Appalachian type, sharply folded, and overturned northwesterly by forces acting from the east.

The pre-Cambrian rocks were folded and eroded—no one knows how much—in pre-Cambrian time, and toward the close of that time a deep north-south depression occupied the position of the present Housatonic Valley, extending far westwardly, and lateral valleys branched from it to the east up the present Tyringham, East Lee, and Dalton valleys.

The great transgression or passage of the waters across the region from the west, which introduced the Cambrian era, admitted water into this valley system, and as it advanced it deepened them so that limestones were formed in the valleys, while just east sandstones and conglomerates were laid down nearer the shore line, and there are many transitions from limestone to sandstone. The waters stretched west to the foot of the Adirondacks and continued east across Massachusetts, surrounding a large pre-Cambrian area which extends from the southeastern part of Worcester County across Connecticut to the mouth of the Connecticut River, and reaching some large land body east of the present coast which furnished the material for the abundant conglomerates that appear in the Cambrian gneiss at Monson and in the Hudson arkose in Hudson and Marlboro and in Worcester County, and stretch far northeast into Maine, marking perhaps an old shore line near which the altered eruptives in the Marlboro region were extruded.

The continued sinking of the land, which sent the shore line so far east, beyond the region here studied, caused the conglomerates to change into sandstones, and these into shales which have now become the Rowe hydromica-schists and which are represented in Worcester County by the Paxton whetstone-schist.

Shales continued to be deposited in the east after the partial uprise of the Stockbridge limestone caused it to be covered by the shales which have become the Berkshire schists and which are continued east in the Goshen and Conway schists, and by the Brimfield schists east of the Connecticut. These may be about on the horizon of the Lower Trenton beds.[1]

The increased folding brought nearly all this area above the level of the sea and produced the Bernardston Upper Devonian basin on the

[1] The Washington limestone, by Dr. C. H. Richardson: Proc. Am. Assoc. Adv. Sci., 1898, p. 295.

Connecticut, and the Worcester late Devonian or Carboniferous basin, both apparently opening toward the north.

For the later movement of folding and crushing, the New York horizontal Paleozoic country is the unfolded "foreland" toward which the folds advanced; the "rearland," or country from which the pressure came, has sunk into the Atlantic off the present east coast; the great bands of granite which cross the middle of the State are the eruptives on the concavity of the folded ranges melting up in the great synclines. Here, in the core of the range and a long way west across the foreland, eruptives of the time of the folding are wanting.

The Connecticut and Housatonic valleys are "graben,"[1] or long narrow areas sunk between faults. These faults bound the intermediate block or "horst" which forms the Green Mountain upland. It is simpler to assign them both to the same pre-Triassic era.

Erosion has since worn the mountain range down to its roots, and the "Cretaceous base-level" thus formed may have extended, with some approach to horizontality, across the area and westward, touching the crests of the Taconics and of Greylock and Mount Washington, to the north and south, respectively. If this be true, all the later irregularities would depend upon the unequal capacity for erosion of the two areas, especially upon the solubility of the limestone. The alternative would be that the great depression of the Housatonic limestone valley was in some large part caused by the later downthrow of the limestone area between faults already established. The former supposition seems to me more probable. It would place the downthrow wholly before the Cretaceous base-leveling.

GEOLOGY.

I have distinguished the following subdivisions of the pre-Cambrian and Paleozoic rocks in the Becket and Sandisfield quadrangles, which are described in this paper.

SECTION OF PRE-CAMBRIAN AND PALEOZOIC ROCKS IN WESTERN MASSACHUSETTS.

SILURIAN.

West of the pre-Cambrian.	*East of the pre-Cambrian.*
BERKSHIRE SCHIST.	ROWE SCHIST.
Chloritic hydromica- or sericite-schist.	Light greenish gray sericite-schist, grading southwardly into a feldspathic mica-schist.
STOCKBRIDGE LIMESTONE (upper part).	HOOSAC SCHIST.
A white sugary marble, often tremolitic, with included schist and quartzite beds.	Dark-gray albitic sericite-(hydromica-) schists.

[1] Suess, Das Antlitz der Erde.

CAMBRIAN.

West of the pre-Cambrian.	*East of the pre-Cambrian.*
STOCKBRIDGE LIMESTONE (lower part).	BECKET GNEISS.
CHESHIRE QUARTZITE.	A light-gray friable gneiss, often granitoid.
White sugary quartzite, often tourmaline bearing.	
BECKET GNEISS.	
A light-gray, fine-grained, two-mica- or biotite-gneiss, often conglomeratic, with subordinate beds of quartzite and schist.	

PRE-CAMBRIAN.

WASHINGTON GNEISS.

Rusty, graphitic, and garnetiferous blue-quartz gneiss, becoming fibrolitic toward the south.

TYRINGHAM GNEISS.

Coarse, highly stretched biotite-gneiss, barren of accessories.

LEE GNEISS.

A perfectly banded, medium, black, hornblendic gneiss, sometimes alternating with a white, fine-grained, often micaless, gneiss.

HINSDALE LIMESTONE.

Coarse, highly crystalline, chondroditic limestone.

HINSDALE GNEISS.

Coarse, granitoid biotite-gneiss, often epidotic.

PRE-CAMBRIAN ROCKS.

INTRODUCTION.

A long series of isolated outcrops of pre-Cambrian rocks occupies the western rim of the high ground which extends from north to south across the eastern portion of Berkshire County and looks down on the limestone valley of the Housatonic. They form the axis of the Green Mountains across Massachusetts. (See map, Pl. IX.)

The most northerly outcrops of the pre-Cambrian within the limits of the State are the area of Stamford gneiss of Oak Hill, north of North Adams, and that stretching along the crest of the Hoosac Range south of the tunnel. These have been described in detail by Professors Pumpelly and Wolff, and their relations to the inclosing Cambrian gneiss have been elucidated in a work which marks an epoch in the investigation of the crystalline rocks of New England.[1]

The Hoosac area is described as consisting of "a coarse granitoid gneiss which forms the core of Hoosac Mountain proper, occupying the

[1] The geology of the Green Mountains in Massachusetts, by R. Pumpelly, J. E. Wolff, and T. Nelson Dale: Mon. U. S. Geol. Survey, Vol. XXIII.

surface of the mountain for several miles, then disappearing below the overlying rock, but cut in the Hoosac tunnel for nearly 5,000 feet." It is called the Stamford gneiss. It is "a coarse-banded gneiss, composed of long lenticular crystals of pinkish feldspar, flattened lenses of blue quartz, and thin, irregular, greenish layers of a micaceous element (biotite or muscovite, or both) mixed with small epidote crystals."[1] It varies but slightly in microscopic and macroscopic characteristics, and Professor Wolff does not attempt to subdivide it in the field or to decide whether it is an eruptive granite or a highly metamorphosed member of a detrital series.[2] Specimens have been taken from the material of this age brought to the surface in the central shaft of the Hoosac tunnel to illustrate pre-Cambrian gneissoid granite in the educational series of rocks distributed by the United States Geological Survey.

All the other outcrops of the series are described in this bulletin, beginning with the Hinsdale area in the Becket quadrangle, which is traversed by the north and south portion of the Boston and Albany Railroad, and extending south across that and the Sandisfield quadrangle. The series continues southwest across Connecticut and New York to the Highlands. Several of these areas extend a little way over into the Sheffield quadrangle on the west, and Professor Hobbs thinks that the Cambrian gneisses are worn through, exposing small areas of the pre-Cambrian, on Warner Mountain in Great Barrington and on Brush Hill in Sheffield. The Canaan Mountain pre-Cambrian enters the Sheffield quadrangle, but not the State of Massachusetts. There are thus twenty-three pre-Cambrian areas in the western part of the State.

These areas change progressively as they cross the State. The Hoosac Mountain area is a monotonous mass of coarse porphyritic, granitoid gneiss of doubtful, but probably eruptive, origin.

The Hinsdale area is a closely appressed and slightly overturned anticline, exposing a nucleus of ancient epidotic gneiss surrounded by a thick bed of highly crystalline, chondrodite-limestone, and this by a band of dark gneisses, while the series is closed by a rusty graphitic blue-quartz gneiss. The whole is in apparent conformity, and no striking unconformity marks its contact with the surrounding Cambrian gneisses. On the west of this anticline the blue-quartz gneiss alone is exposed in the Dalton anticline as the core of a normal fold, in sharpest unconformity to the Cambrian conglomerate.

Widely separated on the east, the Coles Brook limestone band is thrust up irregularly through the Cambrian gneisses. It is extremely long and narrow, and the dark East Lee gneiss accompanies it at its southern end.

To the south of these the broad Tyringham area shows extensive bands of a barren and monotonous coarse biotite-gneiss (the Tyring-

[1] Loc. cit., p. 45.

[2] Loc. cit., pp. 47, 48.

ham gneiss) characterized by such extreme stretching that the biotite masses are drawn out into long pencils, and foliation surfaces of the rock appear as if fingers had been dipped in ink and drawn across them. This is bordered by the Washington blue-quartz gneiss, the upper member of the series, and strips of this rusty blue-quartz rock are infolded as synclines in it, while the East Lee dark-banded gneiss appears as anticlines. When the latter is worn through, the limestone, or the pyroxene-wernerite or actinolite rock which represents it, appears. In the northern part of the Tyringham area the pre-Cambrian is in apparent conformity with the Cambrian gneisses above, but in the southern part it is in plain unconformity with them. In the latitude of Otis village the blue-quartz gneiss begins to be fibrolitic, and this character becomes more and more pronounced toward the south. The broad Sandisfield area is a low dome which scarcely exposes anything except the Washington gneiss—there a rusty fibrolite-gneiss rarely showing blue quartz and allanite, which extends into Connecticut and carries small beds of chondrodite-limestone.

Finally, in the small areas to the southwest, which are exposed by the solution of the limestone and the sinking and removal of the Cambrian gneisses, the rock is still more strongly ferruginous than farther north, and much magnetite, pyrite, and pyrrhotite appear.

From Campbell Falls south long bands of a dark schistose biotite-gneiss occur, which are full of rounded nodules of microcline largely changed to muscovite and full of fibrolite. The same occur in the southern part of the Sandisfield band.

This change in the character and arrangement of the pre-Cambrian rocks has had a marked influence upon the topography of the range throughout its course across the State of Massachusetts.

In the solid block of the Stamford gneiss the pre-Cambrian composes the crest of the mountain range, while farther south its limestones have by their solution formed all the passes across the mountains and many rock-bordered ponds.

HINSDALE ANTICLINE.

A large portion of the towns of Hinsdale and Washington is occupied by this area of pre-Cambrian rocks, which form an anticline closely appressed and slightly overturned to the west. It is 12 miles long and 4 miles wide. For the greater portion of its length its axis is north and south, but it narrows at its southern end and bends southeastward in sympathy with the Tyringham anticline, ending in the river bed a mile below North Becket station. It also sends an irregular fold southwestward past Washington Center. To the north it ends in several lobes projected far into the town of Windsor.

The east-west fault which limits the Dalton anticline on the south extends far into the center of this anticline and nearly bisects it. As a result, it is much more sharply folded to the south of this fault,

forming a compensation for the fold of the Dalton anticline, which is only partly continued in a slight fold south of the east-west fault.

The Hinsdale anticline is taken as the type of the pre-Cambrian areas, since it is the only one which exposes a gneiss older than the Hinsdale limestone and the one which shows the pre-Cambrian rock series in the fullest way. For this reason the names of the different subdivisions have been mainly drawn from this tract.

HINSDALE GNEISS.

This rock emerges from beneath the Hinsdale limestone and lies in the bottom of the Hinsdale Basin. The upper pre-Cambrian gneisses and, in an even more marked way, the Cambrian gneisses form an unbroken line of high hills around it on every side.

The great area of deeply rotted rock which surrounds the Washington station and which was sheltered from the erosive action of the ice suggests that the whole basin was deeply decomposed at the beginning of the Glacial period and was thus in part excavated by the ice.

The only place where it can be studied in considerable outcrops is on both sides of the roads forming a square a mile north of Hinsdale Center. The commonest rock along the western road of the square is a light-colored, well and coarsely bedded, epidote-biotite-gneiss (see detailed description, page 23, and fig. 1 of Pl. I, p. 26). The large, curved-faced feldspars are mostly crushed to a granular mass, and the result is a rock somewhat like the white Cambrian gneiss, but much firmer and coarser and often showing muscovite of secondary origin on the foliation faces. Other beds are compact and massive and show some blue quartz, which is rare in the Hinsdale gneiss.

Farther north along this road the rock is a coarse granitoid feldspar-quartz mass, rudely foliated by distant biotite-epidote films, and in places strongly stretched. Rocks of this type extend north into a great double-topped hill and make up its western crest.

A peculiar altered limestone bed about a rod thick can be followed from north to south along the top of this western crest. It is mostly changed to silicates, among which tremolite in coarse blades forms beautiful cabinet specimens, and a green clinochlore in coarse plates is very abundant. It is in places broken up into a series of great lenses which run along the strike. This is plainly a result of the solution of part of the limestone and the compression of the gneiss around the remnants. One of these lenses is a mass of hornblende-pyroxene-epidote-calcite rock with eozoön structure.

This limestone appears north of the road running southeast from the center of Hinsdale, near the creamery. The rock is a rusty thin-bedded gneiss, with traces of a layer of limestone, now almost wholly changed to a coarse salite-actinolite-graphite-calcite rock. A shaft was sunk 16 feet deep on this rock in 1885, in search of graphite, and later, in 1895,

more digging was done at the same spot in search of iron. The adjacent rock is exceptional on this horizon, and resembles the Washington gneiss which surrounds the basin as the newest member of the pre-Cambrian series. It lies in the middle of the anticline.

On the eastern road of the square, layers of very dark gneiss carrying much biotite and hornblende alternate many times with the common gray biotite-gneiss and are shot through by small pegmatite veins.

This structure is very characteristic across the eastern peak of the double hill already mentioned. Bands of the two rocks only 3 to 10 inches thick and preserving their widths for long distances, alternate regularly, and the lighter rock weathers more easily into deep grooves, bringing out strongly the continuous strike or in places the great contortions of the bed. This bed can be followed south about 2 miles.

The most interesting type of the Hinsdale gneiss and the most accessible outcrops are 50 rods north of Hinsdale station, on the west side of the railroad. The gneiss rests directly upon the limestone, the rocks being there overturned, and dips 35° SE. It is a peculiar, fresh, coarse gneiss of very white color, although it contains a jet-black biotite in considerable quantity. (See detailed description below.)

These rocks seem characteristic of the horizon just under the limestone, and there is a similar curious rock developed on a similar horizon at the northwest corner of the square of roads mentioned above. It is a coarse flesh-colored gneiss made up almost wholly of feldspar, with a foliated structure imparted by widely separated streaks and flat blotches, all stretched in a common direction and containing a dark-green fibrous hornblende, epidote, and dark-brown titanite.

Structure.—There is a marked prevalence of northerly strikes and moderate easterly dips in the structure planes of the coarse gneisses, and when separate beds can be traced they take the same direction. This agrees with the posture of the limestone bed which surrounds the Hinsdale gneiss.

If the limestone bed at the creamery is an integral part of the series, it is not improbable that the whole may be of sedimentary origin. It makes, however, the impression of a very coarse and not greatly altered granite.

PETROGRAPHICAL DESCRIPTION.

Biotite-microcline-gneiss.—Fifty rods north of the railroad station at Hinsdale is a coarse, white, biotite-epidote-microcline-gneiss of granular texture. In its lower layers the fresh black biotite is in widely separated films mingled with epidote grains. In its upper layers the biotite is aggregated into flattened lenticular biotite-epidote masses, placed an inch apart in the foliation planes. The mass of the rock is a dull white mixture of much feldspar and a little pale bluish quartz. It contains pyrite in small pentagonal dodecahedrons and submicroscopic zircons of a dark clove-brown color. The feldspar which forms nearly the whole mass of the rock is uniformly microcline in large cleavage

pieces, which are granulated at the border and included in broad patches of the granulation mosaic. The remaining fragments are strongly and regularly curved in the cleavage faces, but show no trace of the intergrowth of albitic bands. Sections parallel to OP (001) show with the lens small, rounded, opaque spots, which on examination prove to be bodies placed in the intersection of the two twinning systems. They are cylindrical, with rounded ends, and seem to be muscovite crystals elongated parallel to the *c* axis and slightly twisted; often a slight, lateral pressure has changed them into a pile of overlapping scales. An immense number of epidote grains, small crystals, and microlites, and many minute-lobed plates of biotite are evenly distributed. This multitude of inclusions causes the opaque-white look, but there does not seem to be any trace of kaolinization or weathering. It is epidotization due to metamorphism proper.

The feldspar has the complete microcline structure and pronounced prismatic cleavage, and large patches are still untwinned microcline.

The quartz contains a few short, straight, black microlites unlike the long rutile trichites of the granites. The trains of cavities are very abundant, and often run through several grains of quartz, suggesting crushing. They are made up of very small cavities with motionless bubbles unaffected by heat.

Biotite-gneiss and granulite.—Following the railroad a few rods north from the outcrop of the white gneiss described above, one finds in the wall of the railroad cut an outcrop of a dark-gray, stretched, granitoid gneiss of more normal texture and somewhat finer grain than that last described, which abounds in minute garnets, so that as the mica disappears from some layers they become a light-colored granulite.

Under the microscope it is very unlike the former rock. Microcline is almost wanting, and the mass of the rock is a quartz mosaic of irregular grain, with little microcline and orthoclase, with very wavy extinction, and with a triclinic feldspar near albite. The dark olive biotite is raveled out at the edges and changed to chlorite. The small, round, red-brown garnet grains are generally without inclusion and are nonpolarizing. The only remarkable peculiarity of the rock is that large grains of quartz and plagioclase have their centers full of blebs of garnet, quartz, and biotite, while there is entire freedom from nodules or water bubbles. There is every sign of rapid crystallization.

Epidote-gneiss.—Next above the preceding rock is a coarser gneiss, in which greenish layers of biotite, mixed with much green epidote and secondary chlorite in broad, distinct sheets, inclose a fine granular mosaic.

In sections cut across the foliation the microscope shows this mosaic to be made up of elongate-opaque patches, with intervening transparent portions. The latter are a quartz mosaic; the former are portions of a feldspar so filled with minute pale-green epidote that the character of the feldspar can not be determined. The frequency of crushing is

PLATE I.

PLATE I.

FIG. 1.—Hinsdale gneiss, from near N. B. Whitman's house, in the northern part of Hinsdale. The lighter quartz bands are drawn with polarized light to obtain the boundaries of the grains in the mosaic. The darker bands of plagioclase are drawn with common light to obtain a clear view of the minute epidote, biotite, and chlorite crystals. × 14.

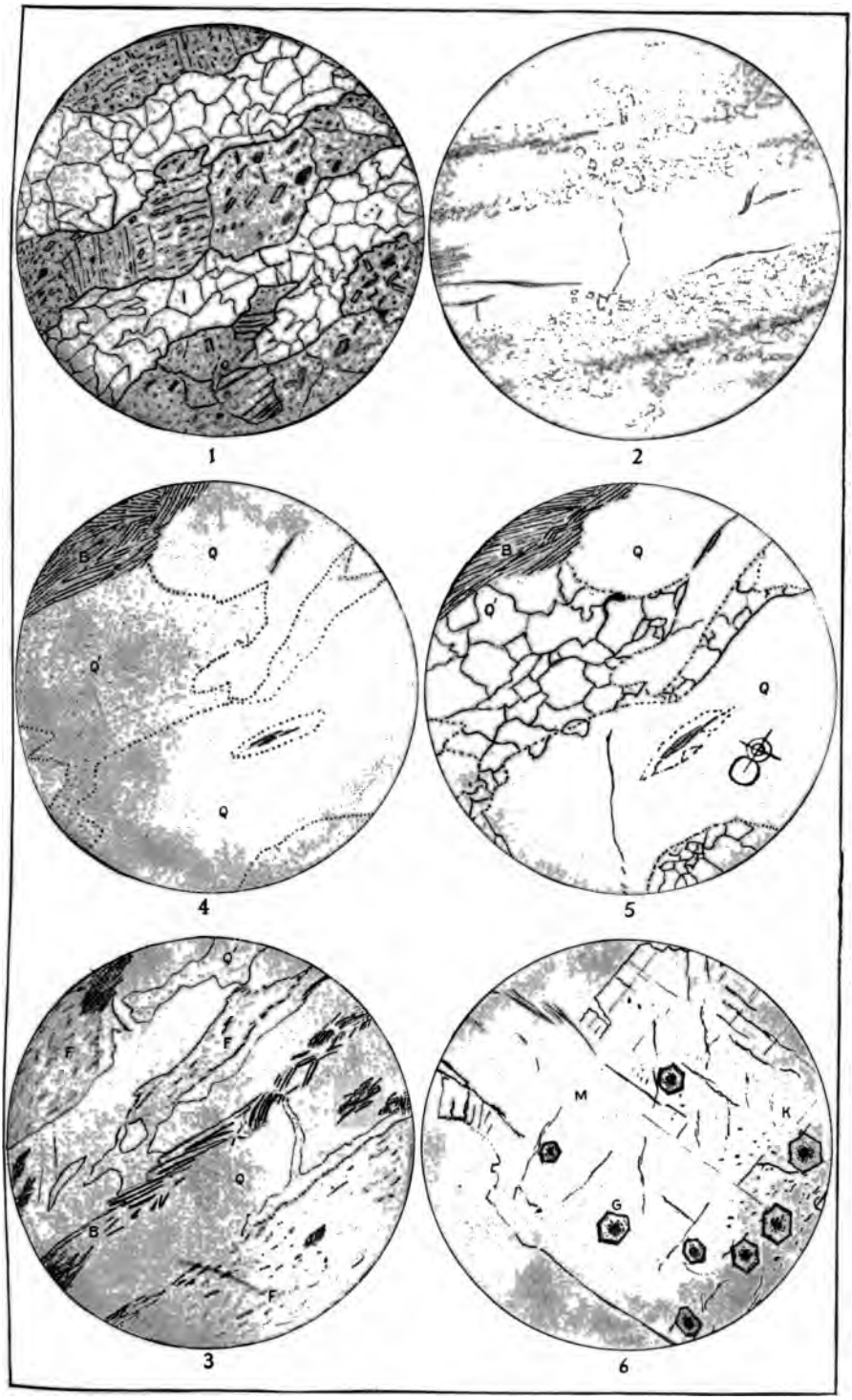
FIG. 2.—Washington gneiss, Peru; H. A. Messinger farm. (Slide F.) The granular bands represent a fine quartz-feldspar mosaic, in which much newly formed muscovite is regularly disseminated in fine scales. The intervening bands are of limpid quartz, which is little fissured. The slide is drawn with polarized light and the strong undulose extinction of the quartz bands is represented by shading. × 14.

FIG. 3.—Washington gneiss, Washington, north line of Pittsfield road. Three bands of a quartz-feldspar-muscovite mosaic (F) and a central biotite-muscovite band (B) are separated by three bands of blue quartz (Q) in the dotted portion of which (Q′) the blue color has been discharged. A well-defined rhombohedral cleavage appears in part of the quartz. × 3, natural light.

FIG. 4.—A portion of the lower part of the upper-quartz band of fig. 3. The dotted portions (Q′) do not show the blue color, but are not otherwise distinguishable, and the cleavage lines run through both portions. × 14, natural light.

FIG. 5.—The above slide (fig. 4) seen with polarized light, showing the coincidence of the crushed and colorless portions (Q′) and of the parts with undulose extinction and those with the blue color (Q). The cleavage lines make an angle of 74° instead of 94°, and the oblique position of the axial cross agrees with this decrease of the cleavage angle.

FIG. 6.—Cyanite (K) changing to muscovite (M) with included garnets (G). Becket, p. 84.



THIN SECTIONS OF GNEISSES AND CYANITE.

shown by the sheets of cavities passing through the quartz grains. These cavities rarely show bubbles, and only the smaller show motion. When heated to 70° C. they are not changed.

Blue-quartz gneiss.—At N. B. Whitman's house, in the north part of Hinsdale, is a granitoid gneiss (Pl. I, fig. 1) in which the small distant aggregates of black biotite and epidote do not much aid the foliation. Pyrite is abundant. Bands of blue quartz, about 1 to 3 millimeters wide and about twice that distance apart, run interruptedly through the rock; they have crushed borders or dissolve entirely into a white mosaic. Between these is an opaque white mosaic of feldspar crowded full of minute epidotes.

The quartz mosaic represented in the figure by the two broad light bands is very fresh. Sheets of minute pores or solid particles pass from grain to grain. Many of the grains have a delicate wavy extinction. The feldspar, which crosses the figure in three bands, is much coarser, and the feldspars are uniformly a plagioclase with extinction 2 degrees to 12 degrees, generally very low, indicating an acid plagioclase. It is very fresh, and the small sharp epidote, biotite, and chlorite crystals are spread evenly over the field, like the small crystals in a micro chemical experiment, giving the band a glistening, satiny look in the thin section. There is no indication of decomposition, but rather of an original formation of the feldspar mass made up of large allotriomorphic grains, a fissuring of it, a subsequent formation of blue quartz in the fissures, and a later mylonitic effect upon the whole. It is interesting that there is here no trace of microcline or orthoclase, but that the abundant growth of the small, sharp epidote, biotite, and chlorite crystals appears equally well in the plagioclastic as in the microcline-bearing rock, and seems in both to be a result of intercrystallization rather than a secondary alteration of the feldspar.

HINSDALE LIMESTONE.

In the more regular portion of the syncline across Hinsdale so many outcrops of the rock have been found that it is quite certain that a heavy band of limestone, often changed in whole or in part to amphibolite, steatite, or serpentine, encircles or did once encircle the lowest gneisses. It is marked by a series of abandoned limekilns, and before the opening of the "Western Railroad" was of economic value. Several of its outcrops were mentioned by President Hitchcock, and Professor Dana[1] called attention to the locality at Hinsdale Station as containing chondrodite, and from this fact assigned these rocks to the Archean—that is, to the pre-Cambrian.

As exposed in the railroad 50 rods north of the Hinsdale station the limestone is a very coarse, wholly crystalline rock—a white coccolite-limestone containing graphite, chondrodite, phlogopite, and coccolite

[1] Am. Jour. Sci., Vol. XXXIII, 1887, p. 275.

in grains, and hornblende in larger masses, some of which are a foot across. Only 25 feet is exposed, and it is covered by the coarse Hinsdale biotite-gneiss. A mile south, where the highway crosses the railroad near a bridge, the bed reappears and continues for a long distance southward by the roadside, more than 100 feet in thickness being exposed. It is here a very coarse crystalline limestone, the grains often 50 to 100 mm. across and multiple twinned, with crystals of bronzy and pink phlogopite 20 to 30 mm. across, and black to pale-green hornblende, clove-brown pyroxene, green coccolite, graphite, and pyrite. It is in places changed into great masses of matted pale-green tremolite, and this can be followed a long way southward as a very impure tremolitic limestone. It appears as a phlogopite-limestone farther south, at the E. Cheesman place, a half mile west of the next railroad crossing. From this point the bed is covered for a long way south, and I have located it approximately on the map by fixing the boundary between the coarse Hinsdale gneisses and the upper rusty gneisses and also by the fact that its course is marked by abandoned limekilns and ponds and swampy areas where it has been deeply dissolved. In the second cut south of the Hinsdale station are great bowlders of serpentine which came from some portion of the bed.

Just east of Muddy Pond, north of Washington Station, the band is represented by the old graphite mine of Washington (see fig. 3, p. 36), which reminds one, except for the size of some constituents, of the graphite vein at Ticonderoga. It contains very coarse calcite, graphite in broad hexagonal plates, coarse white salite, coarse green pyroxene and hornblende masses, groups of finely terminated pistachio-green pyroxene, brown sphene, pericline, adularia, and garnets, followed paragenetically by coarse calcite with phlogopite, and this by quartz. This has been opened 6 rods along the strike and a shaft sunk 25 feet.

A hundred yards of a fine-grained compact gneiss containing much ilmenite, which I associate with the older gneiss, separates this deposit from a thin bed of limestone on the east; these two beds can be traced south, and cross the road, beneath the two most easterly houses on it, as two beds of amphibolite. South of the pond the outcrops are good, and but a single bed of a pyroxene-hornblende rock can be found as the representative of the united beds, and this swells and contracts in a series of great bunches, due to the removal of most of the limestone by solution.

A remarkable outcrop occurs in the eastern band, 50 rods west of the house of O. Bills and 150 rods east of the southernmost railroad crossing in Hinsdale. Here great layers 3 feet thick are made up almost exclusively of red chondrodite and bright-green clinochlore, the latter in plates up to an inch across, and the change into serpentine and talc has taken place on a large scale.

Farther north, at River Bend Farm, below the mill pond on the Housatonic branch, the limestone is exposed at the sawmill with a

thickness of 600 feet and the base is not seen. At top the bed is changed into a compact, firm, granular, apple-green talc for a thickness of 50 feet, and dark-gray slaty serpentine appears here also in bowlders. It is divided by a narrow band of gneiss. The limestone is marked by distant partings of phlogopite and much of it is a fine white marble, faintly banded by dark interrupted streaks. Other extensive outcrops occur farther north, but add nothing to the petrographical characteristic of the rock.

The bed can be traced up to the southern end of the Ashmere reservoir, and the long, deep depression occupied by this pond may be taken as its continuation, and the ruins of an old kiln may be found just beyond the north end of the pond, on a rusty calcite-garnet-hornblende rock.

A mile and a half north, on the northern branch of the Housatonic, is E. Cady's lime pit. Extensive excavations have been made in a bed

FIG. 1.—Section at iron bridge, Windsor. LG, Lee gneiss; HL, Hinsdale limestone; HG, Hinsdale gneiss.

of coarse limestone which has strike, N. 20° E., dip, 45° E. at its south end, and strike, N. 10° W., dip, 65° E. at the north end, where the bed is 83 feet thick, including one rod of coarse hornblende-gneiss. The limestone contains much hornblende and phlogopite. One layer of a dark amphibolite is two inches thick with the bedding.

A most interesting outcrop occurs farther north on the Hinsdale-Windsor road at the iron bridge. This is at the apex of the northeastern lobe of the limestone. (Fig. 1.) A sharp fold of the overlying gneisses exposes the limestone in a narrow band which runs up from the last locality, and whose apex is exposed here on the bank of the brook. The older gneiss upon which the limestone rests appears beneath the latter at the level of the brook and the newer gneiss (the dark Lee gneiss) arches with many faults over the coarse white limestone, and it is very clear that there has been much solution of the latter and adjustment during the folding of the rocks. The Lee gneiss is a white crushed gneiss with large blotches of hornblende and allanite. The

allanite is especially abundant beneath the bridge, and the hornblendic rock appears as a thick bed of a massive black, heavy, white-spotted gneiss in the fine cliff across the road to the west.

To the west of this outcrop is the high hill of black, crumpled, fine-grained mica-schist (phyllite). The lobe of pre-Cambrian rocks which runs up the east side of this hill is matched by a similar lobe running up the west side, and the curved reservoir pond seems to lie in the continuation of the limestone.

The dam at the outlet of the pond is a wavy bed of dark-green amphibolite, which still contains a central band, 1 to 5 feet thick, of coarse crystalline limestone.

A little farther down the brook, and easily reached by a footpath from the Windsor or Wakonah Falls, is an extensive bed of steatite. Here the limestone bed has changed through actinolite into steatite (fig. 2), and the influence of the removal of the limestone is clear. The steatite has been worked out of great chambers, the back walls of which are composed chiefly of gneiss. The gneiss layers can be seen to be

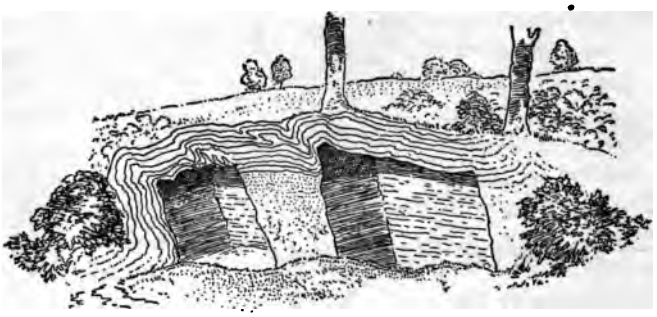


FIG. 2.—Steatite quarry near Windsor Falls, Hinsdale. Gneiss folding round a bed of steatite.

very complexly corrugated in the immediate vicinity of the steatite, and at the left of the figure they bend at right angles and run, with many corrugations, down the whole end of the steatite bed, cutting it off completely. The strike here is N. 30° E. with the plane of the figure, and the dip is 50° E., or from the observer. The gneiss is the white-and-black banded Lee gneiss. Its position plainly indicates that it has been crushed in around the remnant of the limestone bed spared from solution and sharply faulted.

Upon following the limestone S. 30° W. a half mile, to the point where it runs into Dalton and crosses the east-and-west road south of P. Mitchel's, it is seen that the boundary line soon begins to be marked by a great number of serpentine bowlders. Thirty rods north of the residence of D. J. Pratt a great bed of serpentine 3½ rods wide has been quarried and is exposed. It is very dolomitic and slaty; much of it is still matted tremolite and actinolite. It sometimes shows a rich nickel-green color, but is much fissured and worthless.

From this point the limestone bed is concealed, and I have followed

it, by bowlders and by the strike of the adjacent rocks, for a long distance southeast. It occupies—and its removal has, I think, caused—the deep depression at the north and east foot of the high, rocky hill a mile north by east from Hinsdale Center.

The bed appears beside the western road of the square mentioned in describing the gneiss,[1] in a deep excavation several rods long, with an exposed thickness of 20 feet. The black Lee gneiss is in place just west, and to the east is the peculiar titanite gneiss mentioned on page 23. The limestone is a very pure white, coarse crystalline rock, with small bright coccolite grains and much shining black mica. It is peculiar that this mica is arranged in long streaks and blotches in distant planes and exactly simulating the white, stretched gneiss which occurs so commonly just below the limestone.

It is not until we reach the blind road which runs up onto the hill from near the cemetery at the center of Hinsdale that we again come to ledges showing traces of the limestone band; but the Lee gneiss, which is its constant associate, can be followed almost continuously in the high ground of the hill. In the head of the brook bed east of the second house on this road appear great bowlders, apparently almost in place, of an actinolite-limestone which fixes the position of the bed.

PETROGRAPHICAL DESCRIPTION.

Chondrodite-limestone.—At Hinsdale, north of the railroad station, is a limestone which ranges in color from white to pink, a rather coarse (grains 3–5 mm.), highly crystalline rock, with a certain translucency in the grains which immediately distinguishes it from all the other limestones of western Massachusetts and allies it to the limestones of the Adirondacks.

It carries coccolite, phlogopite, biotite, actinolite, chondrodite, pyrite, and magnetite. Generally the coccolite or the chondrodite, or both, are so abundantly and evenly scattered through the mass that it deserves the name coccolite-limestone or chondrodite-limestone, and the accessory minerals are so arranged as to give the mass a distinct foliation, especially where the chondrodite and biotite predominate.

The chondrodite is disseminated through the rock in yellow patches, elongate and parallel to each other, and as in places it changes into black patches, by the admixture of a green mica and magnetite, the resemblance to the boltonite from Bolton, Massachusetts, is striking, especially in specimens of the latter which are changing to serpentine. In large masses it is a rich deep red, like the chondrodite from the Tilly Foster mine. Under the microscope the patches of the mineral are seen to be composed of crystalline grains, fresh and free from inclusions and wrapped around by scales of a pale-green micaceous mineral, without any indication that the one mineral has been derived from the other. The mineral shows strong dichroism, honey-yellow to

[1] Lat. 42° 28′; long. 73° 6′.

deep red-brown. Toward the surface of the ledge the chondrodite weathers to a honey-yellow, opaque, serpentinous mass.

The phlogopite is in small, thick crystals with rounded borders, and has exactly the same bronzy color as the phlogopite from Templeton, Canada. Its crystals are generally surrounded by a band of scales of greenish-gray biotite. Both minerals are fresh, and there is no indication of a transition of one into the other. It has often a beautiful peach-blossom color.

The biotite is often in black scales, at times in isolated crystals with rounded contours, at times bordering the phlogopite in greenish-gray matted scales.

The pyroxene occurs in dark-green grains of coccolite scattered through the limestone, and in small, stout, limpid, emerald-green prisms in the pink variety of the rock.

The magnetite occurs in small crystals and crystalline grains, often associated with the chondrodite; the pyrite is always in small complex crystals.

An analysis of a specimen of this limestone, made in the laboratory of Amherst College by Mr. F. H. Fitts, is here given:

Analysis of chondrodite-limestone from Hinsdale Station.

	Per cent.
Insoluble in HCl	21.96
CaO	41.31
MgO	1.87
FeO	.68
CO_2	34.71
Total	100.53

Actinolite-limestone.—Forty rods north of Hinsdale station, in the canal beside the stone mill, there is a green massive rock of medium grain, showing a paler green massive pyroxene, a darker green fibrous hornblende, and much pyrite.

With the lens the slide shows little chlorite and much epidote, and in a few places the colorless ground appears. Under the microscope this colorless ground proves to be a much-twinned calcite, into which the terminations of the epidote crystals project. Large colorless areas of pyroxene are intergrown with the hornblendic mineral, which varies in appearance from actinolite to tremolite.

In the Massachusetts survey collection No. XV, 168, is a vein or layer of siliceous calcite in gneiss, labeled "Augitic gneiss, Washington, NW. part." It contains a dark-green fibrous hornblende in large blades, derived apparently from a light-green pyroxene which exists in remnants, and also from crystals of a dark-brown titanite.

LEE GNEISS.

The type of the Lee gneiss is found in the hill overlooking East Lee on the northeast, where the rock is a heavy-bedded black gneiss. It is often a flat-banded black gneiss, alternating in thin layers with a white, sugary granulite.

The most accessible outcrops of this rock along the western side of the area are in the bed of the river near the stone mill just north of the Hinsdale station. The light and dark banded gneisses are tough and granitoid, and abound in epidote to an unusual degree. Several varieties of the rock can be studied at this locality:

1. A light-gray, flat, and thin-foliated biotite-gneiss, so much like the newer, friable Becket gneiss that one is surprised at its toughness.

2. A coarser gneiss, with the greenish biotite segregated into broad, distant sheets and containing thin, lenticular layers of a coarse, reddish granite. Under the microscope the bands of granular quartz are separated by bands of granular epidote, which seem to have wholly replaced the feldspar. The biotite layers often contain much epidote and a secondary green chloritic mineral. The trains of pores run through several quartz grains and rarely show bubbles; only the smaller bubbles show motion.

3. A flesh-colored, thin-foliated gneiss, with greenish films and membranes of biotite, breaking with much difficulty and with little regard to the foliation. This grades, by the entire change of the feldspar, into a quartz-epidote rock.

The Lee gneiss occurs in fine and typical development in the high ridge that extends 2 miles north from Hinsdale cemetery. It includes heavy amphibolite beds and alternating bands of a white granulitic gneiss, with distant blotches of hornblende.

By following the main road north from the cemetery a little way past the top of a small hill, 1,040 feet high, large outcrops may be seen in the open field to the left, and here the coarse, white, greatly crushed granitoid beds are distinctly blotched by biotite, and by stretching the biotite is extended in long bands. The rock abounds in blue quartz, while one large amphibolite layer sends off apophyses into the gneiss like an eruptive. Northward, on the crest of the hill 1,720 feet high, the exposures are abundant and the true sedimentary structure is found, together with the secondary foliation produced by pressure. The two have uniformly the same strike, and the latter has generally a lower dip to the west than the former. At the quarry opposite the entrance to Windsor Falls the rock is extremely thin and fissile and superficially resembles the quartzite, but it is really a very feldspathic crushed rock, and carries the dark-green amphibolite beds which are common in the Lee gneiss.

On the Hinsdale-Windsor road, along the east side of the schist area, the rock is greatly rotted in ledges by the roadside, and a little beyond, at the iron bridge, it contains beds of a curious white granulitic rock

with coarse, distant hornblende blotches, while the same rock appears in picturesque ledges in the bluffs to the west.

In contrast with the broad area in the western limb of the anticline north of the Warner Mountain fault, south of this fault the Lee gneiss has a thickness of only 20 rods on the surface, and is concealed from this point south to the hill three-fourths of a mile southeast of Muddy Pond (see fig. 3, p. 36), where it is typically developed, and runs around south of Washington Station and the swampy ground, extending north therefrom in such a way as to render probable the presence of the Hinsdale limestone to the north.

TYRINGHAM GNEISS.

Along the west of the Hinsdale anticline the higher beds are faulted out of sight; along the east they are so covered that the Tyringham gneiss can not be mapped or found with certainty. At the south end of the area it comes in with great force and in most interesting and typical development.

At the deep cutting south of Washington Station the rock is a garnetiferous zircon-bearing biotite-gneiss of coarse fibrous or woody texture, rarely containing great blotches of a shining black hornblende. The biotite scales are wrapped around long quartz pencils, so that it is easy to note the dip and yet difficult to detect any planes of bedding. This peculiar structure of the rocks seems to be an extreme of the stretching common in the gneiss of the Cambrian series, especially east of the Connecticut. It was deformed under the influence of compressive forces which permitted flow in a single direction only. It weathers into a mass of quartz-feldspar rods, which are sometimes several inches long. This weathering is in itself quite exceptional. On the hillside above the cutting and along the road going south, large outcrops of the rock appear; it is crumbling into a mass of coarse granitic sand, and in the long cutting, which is in many places 10 to 12 feet deep, the decomposition extends everywhere below the bottom. This is a protected portion of the pre-Glacial weathering.

The wind blows the decomposed rock away like sand, exposing quartz veins and leaving large, rounded nuclei on the surface. The decomposition brings out in strong relief the peculiar structure of the rock as it falls apart into a pile of quartz-feldspar pencils, or long, flat rods—the expression of the perfect stretching of the fresh rock.

WASHINGTON GNEISS.

The broad outer zone of this large anticline is formed by a rusty graphitic blue-quartz gneiss. It is in the main a biotite-gneiss, rusty from the decomposition of pyrite, pyrrhotite, ankerite, and hornblende.

It has associated beds of a heavy, black hornblende-garnet-gneiss which have been taken for emery, and in the whole circuit graphite is a never-failing accessory, especially in the upper portion, and it is occasionally so abundant as to tempt mining.

Another equally persistent and very curious constituent of these gneisses is a blue quartz in flat laminæ, 1 to 2 millimeters in thickness, which has often a deep tint of rich, purplish blue. It is so abundant as to form more than three-fourths of the mass, and furnishes very attractive cabinet specimens. Allanite is also a characteristic and abundant constituent of the rock, especially in its upper portion, and the puckering surrounding its black or red cross sections constantly calls attention to its presence in the rock.

In every part of the circuit of this anticline, and along the broken crest of the Dalton anticline, I have never failed to find beneath the next succeeding Cambrian conglomerate-gneisses all these characteristics of the top of the older series. Especially down the eastern side, the area above the limestone is marked by several broad bands of the rusty rocks, with intervening bands of biotite-gneiss. The latter rock is often so crushed that it is with difficulty distinguished from the Becket gneiss above, but there is not such a complete transition from the older gneisses into the white gneiss[1] as that described in the Hoosac area. The rusty blue-quartz gneiss is generally a membranous ("flaserig") rock. Nearly continuous sheets of mica scales wind in and out and inclose the blue-quartz lenses and laminæ. When this rock is involved in a crushing later than the formation of the blue quartz, the latter becomes gradually disintegrated at the edges and at last changes to a mosaic of small grains, and the pale-blue tint is lost in the reflections from the many fissures. By a careful search one can usually detect nuclei which show the color, and in this search the pocket lens is a great aid, as the blue color is thus easily distinguished from the blue grays of the quartz from the granites and Cambrian gneisses.

The Washington graphite-gneiss is absent along the whole western side of the syncline, being concealed by the fault and by the westward thrust of the body of the syncline against the resistant mass of the Dalton syncline, until the south boundary of the latter—the Warner Mountain fault—is reached. South of this fault, at the Plunkett reservoir, the Washington gneiss appears, with a width of 2 miles, extending from the top of Warner Mountain, where the Becket conglomerate-gneiss can be seen dipping beneath it, to the top of the low hill which overlooks the great limestone bed 30 rods south of the bridge a mile south of Hinsdale. Its great width is attributable to its low dip eastward and its many undulations. It gradually narrows southward, and in the high hill three-fourths of a mile west of Washington Station it bends westward and forms the great loop which extends west past Washington Center, where it can be conveniently studied.

It is everywhere a coarse muscovite-gneiss, with some biotite, and so abounding in pyrite that it rots into a mass of rusty fragments, and is usually rusty externally. The content of graphite in clear crystalline

[1] Pumpelly and Wolff: Mon. U. S. Geol. Survey, Vol. XXIII, pp. 72, 85.

scales is nearly constant, and its amount increases with the increase in the rustiness. When not crushed it abounds in bands of blue quartz, sometimes 2 to 3 inches thick, which disappear with increasing granulation. This granulation gives a peculiar sandy look to the rock, different parallel layers of crushed quartz being now white, now rusty, as the crushed mass was influenced by the rusting of the pyrite. Small bands of impure limestone, now mostly changed to a pale-green salite-actinolite rock, appear, and the graphite is often so concentrated in them that they have been mined.

Such a bed appears in the brook crossing the road a few rods west of the overhead bridge on the railroad a mile south of Hinsdale, and, as a line of big salite-actinolite bowlders, can be followed a mile farther south along the crest of the hill above the big limestone bed.

The contact on the Becket gneiss is very clear at the signal station on the apex of Warner Mountain, the highest point west of Hinsdale village, but across Washington and Becket to North Becket the Washington gneiss is much of the way wholly crushed and the blue quartz destroyed, and in many beds the content of pyrite is small. Where

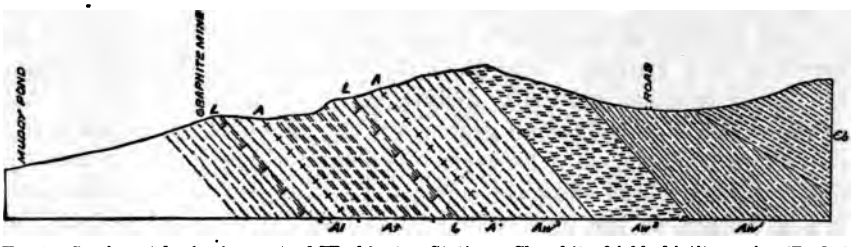


FIG. 3.—Section at lead mine east of Washington Station. Cb, white friable biotite-gneiss (Becket gneiss); Aw¹, white hornblende spotted gneiss (Washington gneiss); Aw², granulite (garnet-gneiss); Aw³, rusty graphite-gneiss; At, stretched biotite-gneiss (Tyringham gneiss); Al, light-gray biotite-gneiss (Lee gneiss); L, limestone; A, amphibolite.

this is the case the graphite is rare, for graphite and pyrite go together. Along this line the Becket gneiss is exceptionally crystalline and coarse grained, so that it is with difficulty distinguished from the Washington gneiss. The Becket gneiss is, however, a pure biotite-gneiss carrying many large garnets, which are absent in the Washington gneiss, and it is rare that a ledge of the latter will not furnish considerable graphite. Along the east side of the area the country is covered by surficial deposits, and the last place for study is east of Washington Station, where the outcrops are abundant.

Following the road from the station a mile east, to a point where it runs north and south, north of a small pond we find the road to be the boundary between the Becket on the east and the pre-Cambrian on the west. Going over the great bare hill we have the following section ending with the lead mine and giving the whole thickness of the Washington gneiss (Pl. I, fig. 3). The great beds of white gneiss are quite exceptional and are exceedingly like the Cambrian at first view. They are, however, more feldspathic, and their scanty black constituent is *mainly hornblende.*

PETROGRAPHICAL DESCRIPTION—CAUSE OF THE BLUE COLOR IN THE QUARTZ.

Blue-quartz gneiss.—At Peru, near the residence of H. A. Messinger, a mile northeast of the bridge over Ashmere reservoir, there is a rusty, fine-grained gneiss (Pl. I, fig. 2), with little mica (biotite) in distant flat sheets of small scales, and with greasy blue quartz in grains and flat plates 1 to 3 millimeters thick, which often coalesce into parallel layers of considerable extent. These layers are plainly secondary infiltrations in a fine granular ground which has the aspect of a fine sandstone or quartzite, while they have much the position of the quartz blades in a graphic granite. In a plane at right angles to the dip they appear as rounded or slightly flattened ends of blades, which have their flat sides in the foliation plane and are often greatly elongated parallel to the dip. Under the microscope this ground proves to be an exceedingly fine-grained mixture of quartz, orthoclase, microcline, and abundant minute scales of muscovite; and it is such a structure as may have been produced by the crushing of granite and the change of most of its feldspar into muscovite. It is shown in three bands, of varying width, running across the slide. The darker shading in these bands represents a concentration of rust which permeates the whole layer.

The blue quartz, which crosses the slide in four bands, contains few minute broken rutile needles, rarely cavities containing small, rapidly moving bubbles, and many rudely parallel sheets of very fine cavities or grains of some unknown mineral. There are a few distant fissures. It shows strong undulose polarization, which appears in broad patches of deep shade elongated with the length of the bands and moving across them. This is indicated by the shading of the bands in the figure. The whole of each of the bands of the blue quartz polarizes as a single individual, however large it may be. The sections were cut at right angles to the foliation and about parallel with the dip or stretching of the rock. It is interesting that in each case they are cut at right angles to the optical axis, and the slide can be moved from one end to another of the blue quartz bands, 1 to 2 millimeters wide and 15 millimeters long, and the optical figure remains sharply defined, regular, and unchanged.

A fragment heated for a long time with the bellows blowpipe retained its color without perceptible change. Even in the thin section the quartz shows a rich blue, like a fluorescence, when examined by transmitted light and without a lens.

At Washington, on the north line of the road to Pittsfield, there is a coarse membranous biotite-muscovite-blue-quartz-gneiss (Pl. I, figs. 3–5). Broad continuous films or membranes of fine scales of biotite and muscovite, one of which runs through the middle of the figure (which represents a transverse section of the rock), wrap around layers or lenses, from a half inch to an inch wide, of a fine granular buff-colored mass, or around feldspar augen. This granular mass, which is shaded in the figure, is a quartz mosaic with very many regularly distributed muscovite crystals replacing most of the feldspar.

The blue quartz, in grains or flat lenses, shows a preference for a position between the membranes of mica and the fine granular groundmass, and seems to be a late addition to a crushed biotite-gneiss. In the figure the blue quartz separates the mica film from the granular mass on both sides. It contains broad sheets of small grains and pores, with moving refractile bubbles and few cracks. It shows undulose extinction, which is represented by the soft shading upon Pl. I, fig. 3. Each band is a single crystal, at least for a long distance, and in the broad band at the bottom of the figure the slide was moved 8 mm. without any movement of the axial cross.

The most striking and instructive things about the slide are, first, that the blue quartz shows, in spite of its great thinness, an opalescent blue color almost as clear as in the hand specimen, and, second, that the blue color is absent in irregular spaces, mostly along the borders, though the quartz does not show any other distinguishing feature and is only rarely separated from the rest by a visible fissure.

In fig. 4 of the plate, which is an enlargement of the lower portion of the upper quartz band in fig. 3, the colorless portions are distinguished from the rest by being dotted and by a dotted boundary. In fig. 5 of the plate the same is drawn with crossed nicols, and it is seen that the portions which were colorless appear, in polarized light, broken into a mosaic whose grains, being relieved from tension, polarize with sharp uniformity, while the blue portions show strong undulose extinction, as is indicated by the central shading. It is thus quite evident that the blue color is due to strain, which is effective in a very thin layer, and that the strain is relieved and the color discharged by the crushing of the mass to a mosaic.

It is curious that a double series of rhombohedral cleavage lines runs through the broadly crushed portion figured and extends beyond it into the uncrushed portion without relieving the tension. The quartz is often crushed at the border and even clear into the center, but with the lens the blue color can be seen until the crushing is complete.

I first found these blue quartzes as grains in the gneissoid Upper Devonian conglomerates of the Bernardston series in West Northfield. Soon after beginning the study of the pre-Cambrian around Hinsdale I remarked the constancy of the blue quartz as a characteristic of the pre-Cambrian rocks of the region. On visiting Professor Wolff I found that he had noted the same thing and had made microscopical examinations of the rocks, and thought that the structure might be caused by strain; but he does not discuss the matter in the final report.[1]

Later, on examining crystalline rock from the southern Appalachians at the Survey office in Washington, I was struck by the prevalence of the same lavender color in the quartz; and finally, in a collection of rocks from Smiths Sound, in the Arctic region, obtained by Hayes and presented to Amherst College, I found a large specimen of the finest blue-quartz gneiss I have ever seen. It is a rich deep blue, like the

[1] *Geology of the* Green Mountains in Massachusetts, Mon. U. S. Geol. Survey, Vol. XXIII, p. 46.

finest cordierite, and is in a layer more than an inch thick extending across a large specimen. I have observed the same thing in the Archean gneiss at Gutwagen in Norway, in porphyries in Finland, and in the granites and quartz-porphyries which extend from Marlboro, Massachusetts, to Providence, Rhode Island.

It is a peculiarity of this coloring that it is best observed with a lens, which detects immediately if it is the true color of the quartz and not a grayish blue depending upon impurities or some fine corrugation of the surface.

The foregoing facts concerning the crystalline continuity of the blue quartz layers and lenses for considerable distances, their strained appearance, and their tendency to form on one side of the mica films, or, as in the center of Pl. I, fig. 4, on both sides, make it probable that they have entered into the composition of the rock at a somewhat late stage, and have since been only partly crushed and incorporated into the general mylonitic mosaic.

An antecedent state of many of these rocks may have been a well-crushed biotite-gneiss, and it is interesting to see how diverse the crushed masses are in the preceding examples.

In one case the rock is a large-grained plagioclase mass, regularly crowded with small sharp epidotes; in another it is almost all microcline, similarly but not so abundantly filled with epidote; in another case the epidotization is carried so far that little feldspar remains; in still another the crushing has changed the larger portion of the feldspar into a mass of small, stout, muscovite crystals.

Except when the large and strongly warped cleavage faces of the feldspar appear still uncrushed, this ground has a very clastic appearance and the blue quartz seems to be connecting thin bands of a firm quartz-sandstone.

This structure in the gneiss illustrates a tendency of the quartz to undergo torsion, or bending, rather than to become granulated under a pressure which would completely crush the other constituents.

DALTON ANTICLINE.

This is a normal flat arch with the Cambrian conglomerate-gneiss worn off from the crest, exposing the upper portions of the pre-Cambrian. (See fig. 4, p. 40.) The crest of the arch runs south from Dalton along the top of Warner Mountain, the north end of which is in Dalton called Day Mountain, and near the line between Dalton and Hinsdale.

The site of the Dalton clubhouse, a mountain house on the top of the high flat hill overlooking the Dalton railroad station, 1,840 feet above sea level and three-fourths of a mile south of Dalton, is a convenient landmark by which to find this most interesting contact of the conglomerate upon the older gneisses.[1] The clubhouse, locally called

[1] For description of the conglomerate contact see page 75.

"the Chalet," is now removed, but the foundations still remain, and the road can be followed from the station, the clearing making a notch in the woods at the top of the mountain visible from Dalton.

The pre-Cambrian, at the contact a few rods southeast of the clubhouse, is a fine-grained crushed granulitic gneiss, but abundant beds of the rusty blue-quartz gneiss come in just east of this. Farther south the blue quartz is everywhere abundant.

Along the boundary, going southwest to the brook which runs through the pasture south of the clubhouse, allanite is an exceedingly abundant accessory in the gneiss, a dozen crystals often appearing in a single hand specimen. It is especially abundant near a large tree at the middle outcrop of the brook bed, indicated in the figure.

A little farther up the brook bed is a very peculiar granular quartz rock containing considerable feldspar and calcite in large, rounded balls, often 3 to 4 inches across, which consist of one or a few crystals

FIG. 4.—Dalton anticline: The Dalton clubhouse section on Day Mountain south of Dalton. Cambrian conglomerate-gneisses arch over the pre-Cambrian uncomformably.

and show very large cleavage surfaces, presenting the finest twin striation. These balls are sometimes blended into masses of very coarse marble as large as a man's head. There is much pyrrhotite developed, especially along the borders between calcite and quartzite, and biotite also occurs in the calcite.

At the south end of the mountain ridge the pre-Cambrian terminates in a fine bluff overlooking the Warner Mountain or South Dalton fault. At the southwest corner it dips under well-marked Cambrian conglomerate-gneiss and shows heavy hornblende-gneiss beds in graphitic blue-quartz gneiss. The southeast corner is three-fourths of a mile N. 20° W. of the signal house on the top of Warner Mountain, and the sudden ending of the blue quartz gneiss against the fault is clearly exposed.

The schist upthrusts in the Stockbridge limestones, which are prominent farther north and disappear in the latitude of Pittsfield, opposite the Dalton anticline, the lesser folding of these limestones compensating for the Dalton anticline.

COLES BROOK LIMESTONE.

A remarkable linear outcrop of the Hinsdale limestone 7 miles long has cut through the Cambrian gneisses like a knife, from Factory Hollow, in Middlefield, to the south part of Becket. It is bounded everywhere by faults, is accompanied by only narrow selvages of the pre-Cambrian gneisses, and, unlike all the other outcrops of the limestone, forms a series of high, steep ridges. It is best exposed a mile northwest of Bancroft Station, in Middlefield, where the Boston and Albany Railroad cuts off a loop of the Westfield River and Coles Brook enters this loop from the north. The Cambrian gneiss overlaps the pre-Cambrian unconformably on either side.[1]

The white Cambrian conglomerate-gneiss in synclinal posture mounts unconformably on the older Lee gneiss, which consists of a great thickness of a wavy bedded gneiss of fine grain and almost black from the abundance of black biotite.

The Lee gneiss abuts, apparently by a fault, certainly by a wholly abrupt transition, upon a band of the coarse, white, almost micaless Hinsdale gneiss, with iridescent feldspar, which is 23 feet wide below but narrows above.

This is followed by a bed of white, thin-bedded, highly crystalline limestone 50 feet wide, with thin films of serpentine, which is separated, by 108 feet of the same dark Lee gneiss, from a second band of similar limestone, of which only 29½ feet are exposed. The partial serpentinization of the chondrodite has here produced a yellowish verdantique which furnishes very beautiful hand specimens and might be useful for ornamental work.

Following this, in the brook bed at bridge 142 and in the railroad cut, is a large mass of the dark gneiss-carrying beds of hornblende-schists, until we come to the fourth telegraph pole from bridge 142, upon the fine unconformity where the conglomerate-gneisses mount the dark pre-Cambrian gneiss.

Between this point and Middlefield Station the cuttings expose a long extent of contorted and twisted rocks, mostly of Cambrian age, the beds swinging round from horizontal to vertical within a few feet.

Gradually a low dip eastward predominates, which becomes steeper, and a band of hornblende-gneiss 10

FIG. 5.—Section of pre-Cambrian rocks at Coles Brook, on the Boston and Albany Railroad, Middlefield. Ahg, Hinsdale gneiss; Ahl, Hinsdale limestone; Alg, Lee gneiss; Ahs, hornblende-schist; €bg, Becket gneiss; p, pegmatite.

[1] The whole section is figured and described by the author in Mon. U. S. Geol. Survey, Vol. XXIX, pp. 21–24.

feet wide sets in, while at the signal house a boss of coarse Hinsdale gneiss and calcareous salite-actinolite-schist protrudes. East of the unconformity all is Becket gneiss, except the few hornblende-gneiss masses and the last-mentioned boss of Hinsdale gneiss, which are brought just above the railroad level by the undulations of the Becket gneiss.

The limestone can be followed a considerable distance north along the brook, and it gradually passes to the east bank. Its most northern outcrops are south of the schoolhouse at Factory Village, in Middlefield, and the long depression, occupied by the pond, which extends north from this point has been formed by its solution. To the west are heavy hornblende-gneiss beds (Lee gneiss).

South from Coles Brook the limestone rises in a great hill south of the Middlefield railroad station, where it is 330 feet thick and is inclosed in a fine granulite.

Westward, toward Becket Center, a ragged, castle-like ledge of calcareous actinolite-gneiss, much contorted, forms the bare crest of the hill south of the road, and just east of this ledge is a bed, 75 feet thick, of a

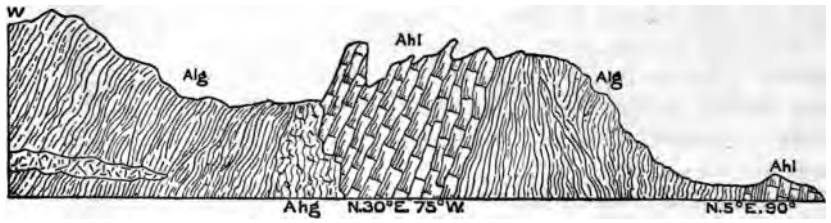


FIG. 6.—The Coles Brook limestone, enlarged from fig. 5.

coarse, well-bedded chondroditic limestone standing vertically. It is full of nodules, often 15 inches across, consisting of salite, tremolite, titanite, and chondrodite. Other nodules are wholly of pale-green bladed tremolite. On the south of this hill the limestone is exposed with a thickness of 250 feet, and farther south, where it crosses the road (at the house of Ellsworth and son), it is 660 feet wide. Where it crosses Walker Brook and the last road on the quadrangle, the limestone is exposed to a thickness of 100 feet, and can be followed south across a blind road, turning south from the main road to a house known locally as "the old Conn place." Just south of this house great masses of the blue-quartz graphite-gneiss accompany the limestone, which can be traced but a little way farther south, as the Becket gneiss closes in on it.

The limestones of this locality are first noted by President Hitchcock in his final report[1] as occurring in the west part of Middlefield on Pontoosuc turnpike, on the railroad at the mouth of Coles Brook, and 1 mile east, in the southeastern part of Becket. The first two localities are on the Coles Brook bed; the third was a line of great bowlders from this bed. The description of the Hinsdale Station limestones

[1] 1841, pp. 81, 85, and 567.

given on pages 27–28 will apply wholly to those of this locality, and the change of chrondrodite into serpentine may be better followed here. The former rock is, however, coarser, and the included minerals are in larger individuals and therefore better fitted for mineralogical study.

LIMESTONE ON THE ALDERMAN FARM IN BECKET.

A mile east of Center Pond, in Becket, a thick bed of pre-Cambrian limestone has been opened. It has a width of 82 feet, and is a coarse chondrodite-phlogopite marble. At its eastern contact is a selvage, 4 feet wide, of pale-green or partly olive-green actinolite-pyroxene rock, which consists for the most part of a loose network of coarse actinolite blades, with some large masses of pale-green pyroxene and pyrite. It contains amethyst, much titanite in the usual flat crystals, and orthoclase in small well-formed crystals with simple forms, rounded edges, and blue opalescence. The bed is bordered on the east by 3 to 4 feet of a dark-banded gneiss of the type of the Lee gneiss, and the whole is inclosed in the Becket gneiss. About 8 rods south (see lower section of fig. 7), in the line of the strike, appears a great bed of a black hornblende-schist, which rests against the vertical Becket gneiss on the east, while the same gneiss appears in its proper place on the west, the intervening space being low covered ground. This hornblende-schist seems clearly to be the continuation of the limestone. It was prospected quite extensively, first for copper and then for emery. A study of thin sections showed it to be a hornblende-biotite-garnet-gneiss, with little black ore and much leucoxene and plagioclase.

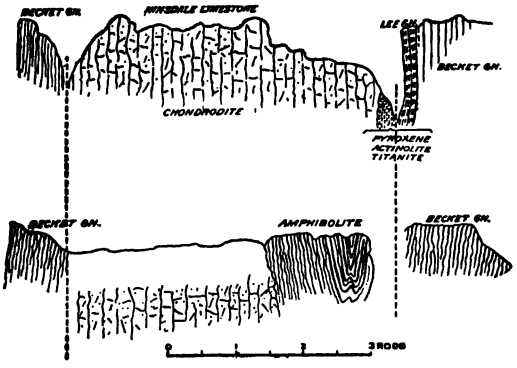


FIG. 7.—Hinsdale limestone at Alderman quarry, Becket. Lower section 10 rods south of upper one.

GULF ANTICLINE, DALTON.

North and northwest of Dalton the country rock seems to be entirely the massive quartzite, but going north by the second wood road, after passing the highest point on the "Gulf road," 30 rods from the highway, one finds outcrops of the gray Becket gneiss. Twenty-five rods above is the coarse, flesh-colored, pre-Cambrian biotite-gneiss, with blue quartz. This can be followed a long way up the brook, to the point where the main wood road crosses the brook, near an old cellar and 80 rods from the "Gulf road." The pre-Cambrian here extends west beyond the woods into the open pasture, and continues in that direction

across 40 rods of Becket gneiss, to the long, bare ridge of quartzite which overlooks the railroad on the west. It can be followed still farther north, to its apex on the high, bare hill, at an altitude of 1,720 feet. Here is a broad, bare hilltop of the Becket gneiss, and at the southwest portion of the flat is the northern apex of the pre-Cambrian—a green, calcareous, highly feldspathic gneiss carrying dark-green fibrous hornblende, titanite, and blue quartz. The Becket gneiss wraps around it, and the contact is perfectly exposed. The Becket gneiss is conglomeratic at the south. A band of Becket gneiss about 40 rods wide surrounds the entire pre-Cambrian area, and the quartzite surrounds the whole. The axis of the anticline runs northeast, and the dips are all southeast, the anticline being overturned to the west. Mr. Benjamin Newell sent me specimens of the fresh rock from a point about 2 miles northeast of Dalton, and a specimen of coarse feldspathic pre-Cambrian gneiss, full of half-inch spots of a biotite-garnet aggregate. This is directly on the line of the axis of the gulf area of pre-Cambrian described above, and indicates a small pre-Cambrian area on the south border of the Greylock quadrangle.

LEE-TYRINGHAM AREA.

DISTRIBUTION.

This is the largest pre-Cambrian territory in western Massachusetts. It begins in a lobe overlooking Sackett Brook, in the south part of

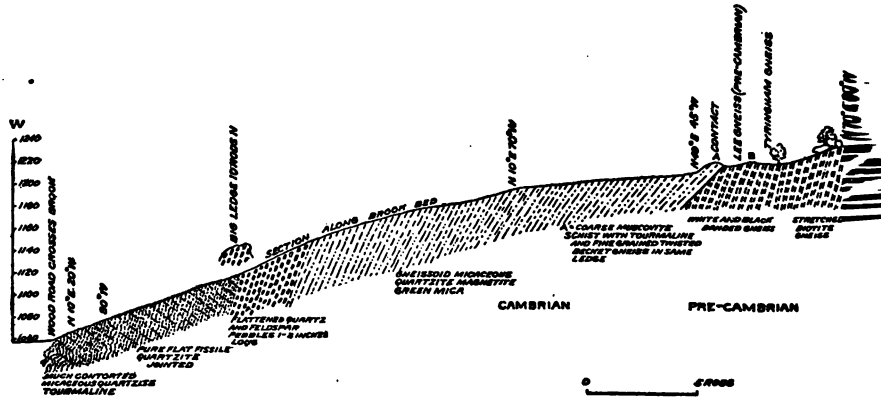


FIG. 8.—Section of contact of Cambrian on pre-Cambrian east of Lenox Furnace.

Dalton, where it is a slightly overturned anticline. It expands between Ashley Brook and Roaring Brook as a normal anticline, with axis running north and south. This is connected by a narrow isthmus with the larger and more important area, which begins on a fault in the high ground southwest of New Lenox, expands rapidly across Washington, occupies all the high ground in Lee and Tyringham, and ends in the great mass of Kingsbury Mountain, against the Tyringham fault.

It is convenient to treat separately the further extension south of this *fault as the* Sandisfield area (see page 55).

BOUNDARY.

The eastern boundary of this area is nearly everywhere normal, being formed by the Cambrian gneisses, which are often conglomeratic. It extends southeastward across Washington, with several great lobes running northward to a point south of Becket Center, where it turns southwestward, becomes an unconformable boundary, and, crossing into Otis, east of where the Tyringham River enters the town, extends southwestward to West Otis, where it meets the Tyringham fault.

Between New Lenox and East Lee the western boundary runs at the foot of the bluff overlooking the Housatonic Valley, and is a line of fault, with downthrow on the west and some westward overthrust. (See figs. 8 and 9.) Along this line the western half of the Lee-Tyringham pre-Cambrian dome is absent, and the Cambrian white gneiss and the lower part of the quartzite are carried down and concealed, the different beds of the pre-Cambrian on the east coming successively into contact with the quartzite on the west. (See Pl. VII, p. 86, and section D E.) East of East Lee the fault bends sharply, influenced by the northward thrust of the country to the south, and in the hill south of East Lee the boundary changes from an overturned and faulted contact to a normal contact, the Cambrian gneiss mounting unconformably over the pre-Cambrian gneisses.

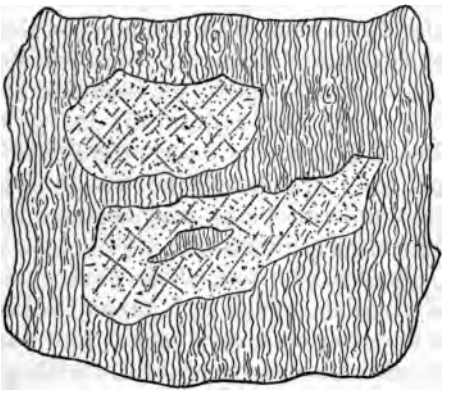


FIG. 9.—Layer of Cambrian slate on vertical Lee gneiss (at B, fig. 8), Lenox Furnace.

STRUCTURE.

Greenwater Pond anticline.—Along its northeastern border the Washington gneiss includes a wide band of Becket gneiss in a normal syncline which extends across Washington and Becket. West of this the Tyringham gneiss crops out over a broad area of great monotony. Still farther west is the curved axis of the important anticline of Greenwater Pond.

Limestones lie along the bottom of the deep valley. The steep walls are composed of the heavy black Lee gneiss, above which the barren Tyringham gneiss extends in low undulations a long way north and south, and finally sinks below the Washington blue-quartz gneiss. The axis of the Greenwater Pond anticline is continued beyond Shaw Pond and ends in the middle of the area, where it is covered by the uncomformable Cambrian gneisses.

East Lee anticline.—A mile east by south of East Lee another small but very interesting anticline, with eastward pitch, exposes the limestone bordered by the Lee gneiss.

Goose Pond anticline.—A mile farther on, Goose Pond lies in the bottom of a curved anticline, with axis pitching south and east at either end, which also exposes the pyroxenic limestones.

The deep valley in which lie Goose Pond, Long Pond, and its tributary brook has been formed by solution of the limestone. It overflowed for a long time into the Tyringham Valley, wearing a deep trench down the mountain side. This valley seems to have been tapped by the wearing back, along the axis, of the East Lee anticline.

The Goose Pond anticline is symmetrical with the Lee-Becket anticline in its Long Pond portion, and bends around in sympathy with the East Lee and Tyringham anticlines in its western portion. It has thus a curved shape like the Bear Mountain anticline (see p. 58).

The axes of these folds end abruptly on the west against the important fault that runs at the foot of the bluff from New Lenox to East Lee, which may be called the Lenox fault. The western prolongation of each of these anticlines was thus dropped below the level of the sea, in Cambrian times, and covered by the Cheshire quartzite and the Stockbridge limestone.

Foxden anticline.—The next interruption to the expanse of the Tyringham gneiss is a broad anticline of the banded Lee gneisses, which begins a mile and a half east of the outlet of Goose Pond, crosses the next road south, with a width of nearly a half mile, and ends unconformably a mile south of this road at a large ruined house, locally called Foxden, overlooking the Tyringham Valley.

The exposures here show perfectly the anticlinal position of the white-and-black banded gneisses in the stretched Tyringham gneiss, and the unconformable overlap of the white Becket gneiss upon the denuded anticline. Only a trace of limestone was found in the core of this anticline.

Hop Brook anticline.—The last interruption to the Tyringham gneiss before reaching the Tyringham fault is the Hop Brook anticline, at the foot of the Tyringham Valley. It is very interesting, both because of the abundance of fine minerals from the limestones of its core which have been found by Mr. Daniel Clark, of Tyringham, and from the light it throws upon the blocking out of the pre-Cambrian valley, into which the deep waters of the Cambro-Silurian sea penetrated, for the deposition of the calcareous beds now altered to the Stockbridge marble.

At the mouth of Hayes Pond, southeast of the valley, is a bed of green pyroxene-actinolite rock 40 feet wide, which, with the associated gneiss, represents the east end of the core of a long, narrow limestone anticline. The white-and-black banded gneisses wrap round the core and pitch steeply east, and can be followed across the pond and up the hill a half mile northwest, where they run under the Cambrian gneiss. They can be seen bending around from a south to a west strike at the house a little way south of the pond, and thence extend west to the

Tyringham fault. The last green actinolite beds of the core are near this house, and the deep erosion of Hop Brook has exposed the core, with many impure limestone beds, still farther west, to a point about 20 rods from the small settlement called Sodom, in Tyringham. They here go under the Cambrian gneiss, reappearing 4 miles down the valley at the Brookside mill, in the village of Tyringham, where, below the dam, the impure pre-Cambrian limestone, with chondrodite, wernerite, and titanite, appears beneath a low arch of Cambrian tourmaline-bearing gneiss, and is continued westward in a small isolated area of blue-quartz gneiss, which is exposed along the road running west down the Tyringham Valley from the mill to the town line. On the hillside above is a thin veneering of Becket gneiss, which has been worn off in the bottom of the valley. Blue quartz occurs in the striking cliffs by the roadside near the town line.

GENERAL PETROGRAPHICAL DISTINCTIONS.

Beneath the white Cambrian gneisses which border the area the Washington blue-quartz gneiss appears everywhere. Below this is a coarse biotite-gneiss, which is quite uniformly free from all accessory minerals and from beds of any different rock type. It is so highly stretched that it shows a ligniform, or small columnar, rather than a common foliated structure. I have called it the Tyringham gneiss.

It rests on a thick bed consisting of well-banded alternations of white granular gneiss and heavy black hornblende-gneiss or hornblende-biotite-gneiss, which I have called the Lee gneiss, and this rests upon the impure limestones which appear in the core of the anticlines.

The Lee gneiss is practically a calcareous facies of the gneiss in the neighborhood of the heavy limestone beds, and it sometimes seems to pass laterally into the Tyringham gneiss.

Hinsdale gneiss.—This rock is absent in the Sandisfield area, as the limestone is nowhere cut through to show the rocks which underlie it. On the road from Lenox Furnace to Washington occur bowlders of a coarse, zircon-bearing biotite-gneiss which closely resembles it but which could not be found in place.

Hinsdale limestone.—The fact, first suggested by Professor Dana,[1] that the removal of the limestone has formed many of the lake basins and valleys in this beautiful lake region, is of great value in the study of the distribution of this rock. The two valleys at East Lee, and the continuation of the more northern across the low col into the Farmington River Valley, Goose Pond, and several ponds in Sandisfield, are illustrations.

Observation is difficult, as the rock is covered by drift and water in bottoms of the valleys and must be studied mostly in bowlders. It is never exposed in beds so great as those in the Hinsdale area and is never so pure as there.

[1] The South Lee, the Hinsdale, and the Tyringham valleys are instanced as showing the influence on the outline of the Stockbridge limestone areas exerted by preexisting Archean channels or bays. J. D. Dana, Am. Jour. Sci., Vol. XXXIII, p. 276.

It is a coarse-grained, greatly gnarled and twisted rock, deeply weathered in the great bowlders which cover the surface where it occurs. It contains pyroxene and hornblende varying in color from deep green to white, phlogopite, muscovite, biotite, chondrodite, wernerite, titanite, chlinoclore, orthoclase, graphite, quartz, pyrite, and pyrrhotite.

Several of these minerals are always present in large amount, in varied and often quite characteristic groupings in different parts of the area. For instance, chondrodite is found most abundantly in masses larger than the two fists on the hill southeast of East Lee, wernerite north of Otis and in the bottom of the Tyringham Valley, and titanite in the northeast corner of Sandisfield, etc.

One mineral common in similar limestones is absent in this region. This is spinel, which is, however, found just south of this district, in Norfolk, Connecticut.

Lee black gneiss.—In the bluffs which border the East Lee Valley on the north and its continuation across Becket occur thick beds of a black, very heavy hornblende-magnetite-biotite-gneiss, which occupies a very constant position above the Hinsdale limestone and becomes a horizon of great value.

It represents a calcareous transition band above the limestone. A thin bed of a rusty graphite-pyrite quartzite seems to separate it from the limestone on both flanks of the East Lee Valley, but could not be found in place.

Along the south side of the valley and on both sides of the next valley to the south, by which runs the road to Goose Pond, the rock is still more strongly magnetitic, so that it is often prospected for iron, especially on the high hill a mile southeast of East Lee. It also abounds in large iron garnets, and this peculiarity can be traced along the north side of the East Lee Valley into Becket. Along both sides an upper bed is leek green and pyroxenic.

This rock also appears in considerable force in the crest of the high ridge north of East Lee, and may be studied by going up the hill road, starting 30 rods east of the East Lee Hotel. At the 1,400-foot contour the woods begin, and at the northwest corner of the clearing are two apparent ledges, which I assigned to the Becket gneiss but found to be great bowlders of the same. From this point a wood road runs up over the black hornblendic gneiss for 30 rods, and the rock ends where this road emerges in a clearing on the crest of a hill. Here it is a black, medium-grained rock, thin splitting and flat bedded. It is an anorthite-amphibolite, and a thin section (No. VI, 131*a*, National Museum Collection) of the black foliated rock cut transversely showed only a trace of quartz, little partly bleached biotite and magnetite, and no titanite. The green, moderately dichroic hornblende is not fibrous, but is in stout, ragged blades appearing in all directions in the slide. The centers of the blades contain many impurities.

The pleochroism is: a = yellow, b = yellow-green, c = blue.

The mosaic of anorthite occupies half the surface; about half shows multiple twinning with large angle of extinction; half the remainder shows concentric extinction, but no twinning. It incloses much hornblende in small plates and in minute straight needles.

The feldspars have very generally a common orientation, so that in the field they show a positive obtuse axis eccentric, with the axial plane about parallel to the twin striation.

There was nothing in the section that would lead one to think it an eruptive, and all its associations connect it with the calcareous gneisses.

A little west of the wood road before mentioned, the rock is white-and-black banded and is greatly twisted in its bedding. Farther west the quantity of hornblende diminishes, and north of the before-mentioned Becket gneiss bowlders it disappears and the rock graduates, with the strike, into the stretched Tyringham gneiss. It can be followed east as far as the limestone ledge, and here also it becomes a light-colored slightly hornblendic gneiss.

It is subordinate to the Tyringham gneiss, but as it borders the limestone areas in the different valleys for so long a distance it seemed well to maintain its distinctness within the area.

Where the band crosses the blind road on the mountain, a mile farther east, at the point where this road runs most northerly, it is a ribbon gneiss of many small hornblende bands interleaved with white gneiss bands.

On the southern side of the valley it can be best studied in the hill south of the hotel in East Lee, and is described in connection with the Hinsdale limestone. (See p. 33.)

It is well exposed along the desolate road which runs from Tyringham Valley over the mountain to West Becket as a series of markedly flat-bedded gneisses, of fine grain, which for nearly a mile across their strike present a continuous alternation of black and white beds from a fraction of an inch to 12 feet in thickness. The white beds have the appearance of quartzite, but are a compact quartz-feldspar mixture which looks as if it had been thoroughly crushed and recemented. The black layers are black from the great quantity of biotite and hornblende, and some beds are a heavy, black granular hornblende rock which resembles crushed tourmaline.

Tyringham ligniform gneiss.—This gneiss is, in perfect development, composed of bundles of quartz-feldspar pencils wrapped round with biotite. The dip is easily obtained but the strike often with difficulty. The rock is best developed across the center of Tyringham on both sides of Goose Pond. It is a coarse biotite-gneiss of very uniform character, barren of all accessories. Its biotite is gathered in elongate films more or less wrapped round the other constituents, and is generally rather dull black. The rock is very prone to decomposition.

Washington blue-quartz gneiss.—The peculiar lavender quartz so char-

acteristic of the pre-Cambrian in the Appalachians is found in all the members except the limestone, but in the upper horizon it becomes extremely abundant and characteristic, so that it is the most constant guide to the settlement of the boundary between pre-Cambrian and Cambrian.

The rock is a coarse biotite- or biotite-muscovite-gneiss. Pyrite is a uniform and often abundant constituent, and the rock is always rusty. Graphite, so uniformly abundant and characteristic of the rock in the Hinsdale area, is found in quantities only part of the way across Washington, but reappears much farther south, in Sandisfield and New Marlboro.

Allanite, which is also abundant in Hinsdale, appears frequently in Becket and Tyringham.

The blue quartz appears in scattered nodular masses, often nearly an inch thick and fusing together into films on the foliation plane, and when the rock contains also large garnets and allanite, with the peculiar puckering around the crystals, it is beautiful and striking. The quartz is often granulated by crushing till only a small center remains, and the color is then wholly discharged. This crushing into a white sugary sand is very characteristic of the rock.

Where it crosses the road north of Ashley Brook it is a very coarse granite-gneiss, like that of Hoosac Mountain. The feldspars are often 4 inches across, at times resembling pebbles and having broad, curved cleavage faces. The blue quartz bands are sometimes 2 inches thick. Other beds are crushed to a fine granulitic rock, with flat, elongate, blue quartz seams.

The gradual granulation, by crushing, of the blue-quartz grains and bands, accompanied by an apparent discharge of the blue color, is very clearly exhibited here in all its stages.

The gneiss along the road from the outlet of Ashley Lake to New Lenox is a coarse to very coarse, granitoid, highly feldspathic, blue-quartz gneiss. Many layers are full of large manganesian garnets, often an inch across. The biotite is in distant membranes, branching out into masses an inch across. It winds in and out among feldspar or feldspar-quartz nodules 1 to 4 inches across. There is often much coarse tourmaline.

LIMESTONE AREAS.

East Lee limestone.—The deep valley which starts at East Lee and runs in a great curve southwest to Otis, containing Greenwater and Shaw ponds, is underlain by Hinsdale limestone and owes its position and shape mainly to the solution and removal of the same.

It is deeply covered by drift, which fills the valley, and can be best studied upon the high, bare hill between the two roads running east from East Lee. It is a coarse, white, highly crystalline limestone, coarser and of more translucent grain than the adjacent Stockbridge limestone, very impure, and coarsely warty upon the surface, from the solution of the purer parts.

It contains actinolite, pale-green and black pyroxene, phlogopite, and, most important, chondrodite, and in the hill above mentioned this mineral occurs in granular masses of the pure substance as large as one's fist and in rude crystals an inch long. Wernerite does not appear in this band, as it is not common in the limestone except near faults.

The mouth of the valley is greatly clogged by thick drift deposits, in which immense limestone bowlders are common, and by later post-Glacial sands, so that the relations of the Hinsdale limestones to the Cambrian deposits to the west can not be determined

The most westerly outcrop of the Hinsdale limestone is the great mass on the south side of the brook just east of the hotel. This is not certainly in place, but the great size of the outcrop and the direction of the glacial movements make it probable that it is in place here or still farther west.

Thirty rods farther west is an occurrence of the limestone in the foundation of a dam. Under the building and near the water wheel it is associated with great masses of the Stockbridge limestone, and this is probably the locality cited by Professor Dana[1] as a place where the two limestones could be seen in contact.

As the Stockbridge limestones dip in three different ways, they are probably bowlders, and from the outcrops to the west it is more probable that the Cheshire quartzite intervenes across the valley mouth, separating the two limestones from each other, as is represented upon the map.

Thirty rods east of the hotel a road runs north onto the mountain, and beyond the single house by the field road leading to the top of the clearing many outcrops appear in the wall at about the 1,400-foot contour. Above the northeastern corner of the east field is a cliff with a fine spring at its foot. For several feet from the base of the cliff the rock is the warty, impure limestone carrying chondrodite and green actinolite. It grades above into zigzagged strata of white, coarse, micaless, granitoid gneiss containing layers and wisps of green actinolite. These beds are together about 15 feet thick and grade upward into a fine-grained, flat-bedded gneiss much like the Cambrian gneiss. It is the transition to the Lee gneiss.

The great bowlders of the coarse limestone are very abundant for 2 miles up the East Lee Valley, to the point where the brook crosses the road to run north, but outcrops rarely appear.

The presence of these bowlders, the continuance of the bordering Lee gneiss in the hillside north and south, and the deep, continuous valley form the ground for believing that the limestone continues along the bottom of the valley.

Goose Pond limestone.—The limestone is almost wholly buried beneath the waters of the ponds, and the barren, stretched Tyringham gneiss appears in the heavily wooded and till-covered banks. In several

[1] On Taconic Rocks and Stratigraphy: Am. Jour. Sci., 3d series, Vol. XXIX, 1885, p. 205.

places the coarse chondrodite-limestones and the coarse pyroxene rock which replaces them form the shore, notably at Elwells Rocks, on the south side of Long Pond toward its eastern end. The superjacent hornblendic Lee gneisses appear in force at the end of the blind road south of Greenwater Pond.

Hop Brook limestone.—Starting 20 rods above the dam, at the small village of Sodom at the head of the Tyringham Valley, the bottom and steep banks of the brook show ledges and large bowlders of a coarse limestone which is more often a coarse-grained aggregate of silicates, both anhydrous and hydrous. Around the village of Sodom itself and at the foot of the steep cliffs farther east many large blocks of the same rock appear, which seem to have been brought down by the torrents of the brook, as they lie far north of the pre-Cambrian outcrops in a direction opposite to the trend of the ice in this region.

At the entrance to the road that leads to Sodom stands the house of Mr. Daniel Clark, whose splendid collection of minerals from the valley and large store of knowledge of the mineralogy of the country will be placed at the service of any student.

The outcrops are mostly concealed in the steep, moss-covered banks of the mountain brook, and they have been exploited at much expense by Mr. Clark. I spent several days studying his collections, and the special peculiarities of the minerals which occur here are described in the mineral lexicon appended (pp. 103–127).

The masses of white, granular quartz-calcite mixture, with small amount of green pyroxene, titanite, and tourmaline from the altered limestone, are catalogued by President Hitchcock as "augitic gneiss from Lee and Washington," in catalogue of Massachusetts collection, under gneiss, 92 to 95.[1]

"Mortised rock" of Tyringham.—At Tyringham quartz pseudomorph after plagioclase is found, penetrated by square cavities from which salite has been removed. (See Pls. II, III.) In these most remarkable specimens great masses of clear vein quartz are penetrated by square cavities from which large crystals of salite have been dissolved, while the quartz proves to be pseudomorph after large masses of plagioclase, presumably albite.

The replacement is so delicately perfect that the twin structure is perfectly preserved, exactly as in cleavage surfaces of albite. This twin striation appears over large areas and is absent over other large areas, and the alternation occurs both in the direction of and at right angles to the striation.

Moreover, the pearly luster of the 0 (001) face is perfectly reproduced in the fractured surface of the quartz, showing that the replacement has preserved the structure of the albite, on which the pearly luster depends; that is, repeated separation along the cleavage planes and

[1] Rept. of Mass. Board of Agric., Appendix, 1856, p. 51.

MORTISED ROCK; QUARTZ PSEUDOMORPH AFTER ALBITE, CONTAINING CAVITIES OF SALITE CRYSTALS; TYRINGHAM.

MORTISED ROCK; QUARTZ PSEUDOMORPH AFTER ALBITE, SHOWING TWIN STRIATION AND PEARLY LUSTER, WITH CAVITIES FROM WHICH SALITE CRYSTALS HAVE BEEN REMOVED; TYRINGHAM.

the formation of air-filled interspaces which have *the effect of Newton's* rings.

Many of the quartz fragments split into large, acute, wedge-shaped pieces, which are aggregated in alternate arrangement of the separate wedges exactly like the Clevelandite variety of albite from the tourmaline-pegmatite veins.

The Tyringham specimens present an interesting and complete series, showing the alteration and disappearance of the pyroxene. There are, first, masses in which the long, white, four-sided prisms of salite, sometimes slightly truncated at the edge and distinctly striated on some faces, are from a half to a quarter inch in thickness and several inches long, loosely aggregated, and passing into a compact salite rock.

There are other specimens in which the same white prisms are inclosed in white or smoky quartz. They show the very strong basal parting of salite, and are often an inch across. They can be seen to be in some places wholly or partly replaced by a secondary tremolite or pale-green actinolite, and the quartz shows distinct traces of the tabular form and the twin striation of albite.

In other specimens the whole or almost the whole of the salite is dissolved, and the cavities take sharp casts of the longitudinal striation of the crystals as well as of the transverse partings which cross the cavity with the proper obliquity of the basal section of salite.

These specimens were found at Sodom, in the upper end of the Tyringham Valley, in the pre-Cambrian limestone. I was therefore greatly surprised to receive from a student a large specimen of the same cavernous quartz, which was found by his father, Mr. Charles T. Barker, during the digging of the cellar under the Berkshire Life Insurance Building in Pittsfield. It is a wholly unworn block 6 inches on a side. The angular faces look as if they might have been broken artificially, and the weathered surface of the block suggested that it had been buried many years. It is full of cavities, some of which are an inch across and 6 inches long. A 6-inch surface shows over half its area a fine representation of the albite cleavage, and half the rest has the appearance of the pearly feldspar cleavage; yet the whole is a clear, translucent quartz, from colorless to smoky, and splinters broken off from the surface showing striation displayed the perfect optical figure of quartz very obliquely placed. I can not imagine that the specimen was brought to its present place by ice, for the proof of its pre-Cambrian origin is quite complete and there is no pre-Cambrian limestone area to the northwest.

From the interest which these mortised stones have created in the past I imagine that the specimen may have come from the Tyringham Valley and have been at some time a part of a collection in Pittsfield, as the place where it was found adjoins the former habitation of the Berkshire Historical Society. This is the specimen figured in Pl. III. Mr. Daniel Clark, who has collected most of the specimens upon which the fore-

going description was based, has written me as follows concerning the Pittsfield specimen:

The specimens have never been found except as drift. I have never seen any ledge, but they occur in numerous specimens from small size to several tons. They could not have drifted far, for they were angular and showed no signs of erosion, and were found on a few acres in Sodom.

The specimen which Mr. Barker found in Pittsfield I believe to be from this locality. Over forty years ago Mr. Stephen Reed, of Pittsfield, who was interested in minerals, visited my place, and I gave him several specimens of what we then called mortised rock, and I believe your specimen from Pittsfield is one of those Mr. Reed carried from here at that time. I have never known of any specimens being found in Berkshire County except in this locality.

Metamorphosis of the pre-Cambrian limestone and paragenesis of the limestone minerals.—The following tabular statement, derived from study of the Hop Brook and Otis limestones, may make clear the probable steps by which the rich mineral beds along Hop Brook have been formed. That this has been along a line of faulting has had much to do with the complexity of the result. A detailed description of all the minerals mentioned is given later:

First stage: A fragmental limestone.

Result of vital forces and transportation. The bed was at first presumably an accumulation of animal remains ..... First calcite

Second stage: A crystalline limestone.

Result of circulating carbonated waters with heat and pressure. In its least-changed state the bed is now always highly crystalline—has recrystallized many times in every part ..... Second calcite

Third stage:

(*a*) East Lee facies. Chondrodite-phlogopite-limestone, with much clinochlore, coccolite, and graphite.

Result of circulation of heated waters carrying silica and fluorine. Characterized by very basic magnesian fluosilicates.

(*b*) Otis facies. Pyroxene-wernerite-titanite limestone.

Result of more intense dynamic and thermal activity along fault planes and the circulation through the limestone of heated waters containing fluorine, chlorine, and titanium compounds.

Characterized by graphite, green and white pyroxene, stout black hornblende, great blocks of wernerite and chalcedony, opalescent orthoclase (loxoclase), albite in great masses inclosing salite and calcite, and pink, white, and gray calcite in coarse crystals ..... Third calcite

(*c*) New Marlboro-Norfolk facies. A limestone containing the minerals of *b* with wernerite replaced by spinel and nickeliferous pyrrhotite.

Characterized by abundant aluminous silicates, which may perhaps be derived from clayey limestones, while the chlorine may come from the ancient sea in which the sediments gathered, and the graphite from the organic remains. The abundant titanite was probably brought into the limestone from without, and this makes it possible that the same may be true of the alumina silicates.

Fourth stage: The mortised rock (*a*).

Extensive pseudomorphic replacement of albite by quartz (see Pls. II, III) without affecting the inclosed salite; resorption of salite for the formation of actinolite, which incrusts the remnant of the salite.

Result of continued action of silica solutions under changing conditions of heat and pressure.

Fifth stage: Quartz inclosing actinolite.

Extensive development of large biotite crystals in veins in which the crystals are greatly crumpled by later movements on the fault. Result of silica solutions at lower temperature.

Sixth stage: Zeolitization.

Formation of scolecite by the decomposition of wernerite. The formation of actinolite continues.

Seventh stage: Zeolitization, continued.

Development on the earlier scolecite of heulandite, stilbite, scolecite, laumontite, and calcite. Formation of jasper inclosing fragments of earlier silicates. Result of warm waters and long time.....Fourth calcite

Eighth stage: Decomposition and hydration.

Jefferisite from biotite, kaolin from feldspar; solution of calcite and etching of crystal faces. Formation of chalcedony inclosing jasper. Effect of atmospheric waters and moderate temperature.

SANDISFIELD AREA.

The long and peculiarly shaped area of pre-Cambrian rocks lying south of the Otis area and the extension of the Tyringham fault down the valley of Clam River and across Sandisfield and Colebrook, is composed almost wholly of the upper member of the series—the Washington gneiss.

In the center of the southern lobe only, where it is widest, is there a trace of the green pyroxene-hornblende rocks, usually associated with the Hinsdale limestone. The most striking occurrence within the area defined above is found at the northwest corner, in the pasture opposite the house of the mineralogist, Mr. D. Clark, at the head of the Tyringham Valley. In the western part of the pasture the white Cambrian gneiss abuts unconformably against the pre-Cambrian gneiss. The blue-quartz gneiss near the house is so full of allanite and its decomposition products that often a dozen crystals appear in a single hand specimen. In tracing these gneisses down from the north this has been found to be characteristic for a long distance. Allanite does not appear much farther south, but is replaced by fibrolite.

Along the west boundary, 2 miles south of Mr. D. Clark's, at a point a mile west of West Otis, just where the boundary line cuts the line of long. 73° 10′, is a beautiful unconformable contact of the Becket gneiss on heavy beds of chondrodite-clinochlore-limestone, which is very pyroxenic and has a broad border of green pyroxenite. It is a medium-grained white marble, banded in places by black ore, and occurs in sufficient quantity to suggest a possible quarry stone.

The hill 1½ miles south by west of Sandisfield, which forms the apex of the pre-Cambrian lobe extending northwest from South Sandisfield, presents peculiar conditions. In the hollow of the north foot of the hill (south of the road) is a typical Cambrian quartzite, at first massive, then, three rods south, banded granular, with magnetite grains, which further south grades into typical Becket gneiss. Two or three rods south of this, in the north foot of the hill, is a 6-foot band of white fibrolite-gneiss, which is continuous with the coarse, crushed Washington gneiss

and impregnated with a coarse feldspathic pegmatite in veins and irregular masses.

All along the tortuous boundary the limit of the Washington gneiss can be fixed by the presence of graphite and fibrolite in a two-mica rusty gneiss, and over the whole area the same characteristics exist, although there are many bands from which pieces much like the Becket gneiss can be taken.

A mile south of South Sandisfield, near a watering trough, a black pyritous quartzite occurs, which is like that above the limestone in the East Lee Valley.

At the southern apex of this area a pale-pink garnet is abundant and of large size. The regular intergrowth of muscovite and biotite is quite characteristic.

Bands of black hornblende-gneiss and green pyroxenite occur just north of the State line in Sandisfield, south of A. Ducharne's house. This rock is rather bright-green, finely granular, and passes into a light granular quartzite made up almost wholly of cuboidal grains of bright-green pyroxene, with distinct dichroism to pale-brown in basal sections and with very coarse prismatic or pinacoidal cleavage. Some grains are centrally darker in color and full of dark ore grains. There are a few grains of orthoclase, plagioclase, biotite, a green mineral like epidote, and a deep-green actinolite. This rock contains no calcite, but it is clearly one of the derivatives of the limestone and is changing into an amphibolite.

In one instance, in the neck that connects Seymour Mountain with a rocky spur projecting southwest, distinct pseudoconglomerate structure appears in the graphitic gneiss. The same rock composes the whole top of the hill west of Seymour Mountain.

Above the 1,600-foot contour the entire hill is composed of coarse, warty, very micaceous gneiss, with rusty, coarse, sandy grained mass. The nodules are about the size and shape of pecan nuts and consist of coarse blades of overlapping muscovite and biotite, often with more or less dark gray from spots of radiated fibrolite. They are first orthoclase, then muscovite, then fibrolite.

The contacts can be well seen at the bridge over Buck River, a mile above West New Boston. The first reefs below the bridge are of Washington graphitic gneiss. Six rods farther is the contact with the thin-banded Cambrian gneiss. The contact is exposed again where the rock crosses the two roads northwest of Seymour Mountain, on the mountain itself and on its southeast spur, as given above, and where it crosses the brook east of Mount Pisgah, on the south line of the quadrangle.

OTIS AREA.

This area is cut off on the south side by the Tyringham Valley fault, which is continued down the valley of Clam River; on the north side it is bounded by the East Lee Valley fault, which follows the bed of

Farmington River. Between these two faults there is a central band of Hinsdale limestone and its derivatives, flanked on either side by the rusty blue-quartz gneiss.

On the west, at the north foot of Filley Mountain, fibrolite begins to appear, and ultimately replaces the blue quartz farther south. On the top of the mountain the two occur together, but the blue quartz can not be traced much farther south as an important constituent.

The eastern boundary seems to coincide with the Farmington River, and the first outcrops to the east, in the high banks, are of the Cambrian white gneiss, until, in the bluffs across the brook south of the blind road at P. Davison's, there is, at an old mine said to have been worked to a depth of 10 to 15 feet, an apparent outcrop of a pyritous wernerite rock of pre-Cambrian age. It seems to lie a little west of the bluffs of white gneiss.

The boundary then runs southwest into Sandisfield, and at the south foot of the hill, 40 rods west of H. S. Hawley's, the last house before turning off to Cold Spring, is another old mine. A deep trench runs into the hill where the white gneiss on the east and the rusty, graphitic, pyritous gneiss full of garnets and black hornblende (this is the ore) on the west are closely approximated.

The next point where the two can be seen to approach each other is on the hill west of the south end of Spectacle Pond, in Sandisfield. The apex of the hill north of an abandoned house is of the white gneiss, standing nearly vertical, with the strike shifting from north around to west, in great folds, from the influence of the fault to the south.

The western boundary is normal. The rusty gneiss rests against the white gneiss and is overturned to the west.

The boundary of the pre-Cambrian on the Cambrian is carried, both on the northwest and on the southeast, directly across the strike of the two, while whenever the two are found in immediate contact they are squeezed into superficial conformity. This is because of the lack of sufficient outcrop. If one could trace the whole boundary, I have no doubt it would run northeast in general direction, but with many sharp serratures directed northwest and southeast.

The bottom of the Farmington River Valley in Otis abounds in large bowlders containing, in great abundance and often in very fine crystallization, the following minerals: wernerite in white stout crystals and large lavender masses, pale-green pyroxene in cleavage masses several inches across, titanite, hornblende, emerald-green actinolite, pyrite, and graphite.

On the hill a half mile south of the hotel is an outcrop of coarse, granular, scarcely cemented limestone, carrying red-brown titanite and grains of wernerite and coccolite, deeply excavated by weathering, from which, tradition says, two cart loads were once blown out by a mysterious explosion while the owner of the farm was in close proximity to the place.

A bed of coarse gneiss, with a band rich in hornblende and titanite, is the southeastern apex of the pre-Cambrian rocks. Everything indicates an overturned anticline of the older rocks included in the Cambrian Becket gneiss.

The Becket gneiss is abundantly exposed over broad areas to the east and north, and strikes N. 20 to 30° W. and dips 30 to 40° W. under the pre-Cambrian. On the eastern slope of the east spur of Sky Hill the Becket gneiss rests, wavy and irregular, on the older rock, which is a stretched gneiss of light color with large grains of magnetite.

At the top and at the east aspect of this hill the typical rusty, blue-quartz, graphitic gneiss is in great force—a ragged-surfaced, well-banded, rusty-brown rock.

The bedding is expressed by bands almost an inch apart, which, being more quartzose, stand at a regular uniform level, while the intervening micaceous layers are deeply excavated by weathering, making a very rough surface. The rock is always very rusty, and at times shows an abundance of lavender quartz, but is usually so crushed that only a blue core can be seen here and there.

The boundary is beautifully exposed around the north slope of this east spur, and runs 5 rods south of two great dead trees which are visible from the whole length of Tyringham Valley below. It then runs northwest, past a large cellar of the abandoned Shaker settlement at the 1,700-foot contour northwest of the summit of Sky Hill.

All of Sky Hill for 100 feet down is of the same rusty rock. A great band of black, heavy, hornblende rock runs across the crest of the hill, and west of it is a micaless gneiss with the aspect of a quartzite. A hundred feet down the slope on the west is a very rusty, extremely graphitic schistose gneiss. All these beds are pre-Cambrian.

Going down the mountain to Fernside we pass over the whole Cambrian and Silurian series inverted, and then over the Silurian and Cambrian in normal order, and come upon the pre-Cambrian in the bottom of the valley. In order to understand this complex syncline one should consult the sections of Bear Mountain in the Housatonic folio.

MONTEREY AREA.

As a result of strong overthrusts to the west a small pre-Cambrian area appears on the south line of Monterey, between two brooks. Its south end is in New Marlboro, at the brook which crosses near the house formerly occupied by E. R. Smith, 2½ miles south of Monterey.

Here the section in fig. 10 is exposed. Beneath the dam the Becket gneiss is in place, with traces of pebbles 1 to 5 inches long. This gneiss is continuous in the field northeast of the house, and contains the beds of amphibolite which mark the neighborhood of the Cambrian contact. The rock dips northeast and seems conformable with graphitic gneiss, which appears in the yard of the house and can be traced into the great hill of pre-Cambrian rocks to the north. It is overthrust

onto the Stockbridge limestone, which appears *in great force west of* the house and to the south grades into mica-schist.

On the hill to the north the blue-quartz gneiss is abundant, associated with coarse graphitic gneiss. Coarse black hornblende in large cleavage pieces, rusting to red in the center, and a dark-green pyroxenic rock with remnant of limestone, also occur here.

All along the northwestern border is a sugary crushed rock, almost wholly fine granular plagioclase, with a uniform small amount of magnetite, and at times minute garnets, a little biotite, and films of muscovite. It carries also lenses of deep-green to black coarse hornblende, with centers of the coarse calcite from which the silicate has been derived. The whole is a crushed facies of the pre-Cambrian limestone on the fault.

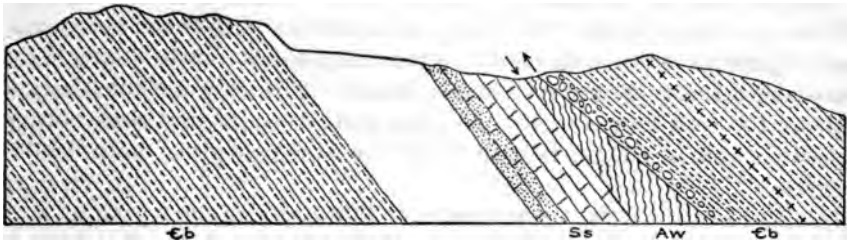


FIG. 10.—Overthrust of pre-Cambrian on Stockbridge limestone; north line of New Marlboro. Cb, Becket gneiss; Ss, Stockbridge limestone; Aw, Washington gneiss.

SOUTHERN AREAS.

The small pre-Cambrian outcrops which run south from New Marlboro village to the southern line of the town are everywhere very rusty and have often tempted the landowners to unremunerative mining, as at the Cleveland, Hotchkiss, and Wadsworth mines. Bands of impure limestone are abundant and have often been changed, more or less, to silicates. Calcareous amphibolites and pyroxenites are as a result common, and often carry a nickeliferous pyrrhotite, which at the Hotchkiss mine has furnished fine crystals.

The limestones are characterized by the abundance of sulphides of iron and by the absence of the finely crystallized silicates, of wernerite, and of various forms of chalcedony, which appear farther north, where the beds are cut by great faults.

The pre-Cambrian rocks lie in whole or in part in deep landlocked depressions, which seem to have been formed by the removal of the limestone by solution, the sinking in of the thin, flat Cambrian cover and the later removal of its fragments. The last stages of this work of removal we may ascribe to the action of the Glacial ice.

NEW MARLBORO AREA.

A mile southwest by south of Southfield, at the house of G. Lawrence, the Becket gneiss, with a band of black hornblende-gneiss, crosses the road.

A few rods north are large cliffs of the rusty, very graphitic gneiss,

with pale-green hornblende, and the boundary can be followed from there N. 60° W., making a sharp loop where it crosses the border of the quadrangle and then going northwest over the north flank of the hill, passing thus into the Sheffield quadrangle. It again enters the Sandisfield quadrangle on Collins Hill, where the Cambrian gneiss is beautifully conglomeratic,[1] and runs along just south of the road into New Marlboro and through the village to a point near a small dam east of the town.

On Collins Hill the pre-Cambrian gneiss contains the blue quartz which is so characteristic farther north.

AREA SOUTHEAST OF SOUTHFIELD.

High bluffs of the light Becket gneiss rise north of the house of J. Wade and occupy the hill to the south of it, and between emerges a small pre-Cambrian area, mainly in the valley bottom, but rising a little above it a short distance west of the house. This area is a flat triangle about 100 rods long and 40 rods wide, and along its northeast border rises a band of coarse, impure limestone and pale-green hornblende-gneiss.

HARMON POND AREA.

The banks on the east side of this pond descend almost vertically into deep water, and 3 feet above the water's edge the pre-Cambrian emerges from beneath the Becket gneiss as a band of green amphibolite with a thin band of coarse, loose, granular, coccolite-chondrodite-limestone, and a micaless gneiss with titanite and chlorite pseudomorph, apparently after titanite. Bowlders of the pre-Cambrian rocks are found around the pond, but the first outcrops in the bluffs back from the water are Cambrian. (See section of Cleveland Mountain shown in fig. 11, p. 64.)

SOUTHFIELD CEMETERY AREA.

A little way up the hill from the Southfield cemetery, a mile south of the village, is a ledge by the roadside where the extremely rusty character of the rock has tempted somebody to waste time in blasting, and the ledge has been so undermined that the rock can be seen to form a low dome. Outcrops of the Becket gneiss are near at hand on all sides, showing that it is a very limited area domed up through the newer rock, which is an exceedingly rusty dark-green pyroxenite, largely hornblendic.

HOTCHKISS AREA.

Northwest of East Pond in New Marlboro, a few rods north of the house of Mr. I. Hotchkiss, a bed of massive, white, coarse limestone emerges from beneath the Becket gneiss, which is at this point a fine quarry granite, and a limekiln has been erected here. The limestone dips 25° N. on the north side of the quarry and 20° S. on the south side.

[1] My attention was called to the locality by Prof. William H. Hobbs.

It is exposed with a thickness of 10 feet, and no bottom appears. It is exceptionally pure; a few small chrondrodite grains and pale-green chlorite flakes occur.

At the edge of the brook, a half mile below the house, a shaft has been sunk about 12 feet upon a group of small pyrite veins in the coarse, rusty, dark-green pyroxenite. Crystals of pyroxene an inch across can be found, generally eight-sided prisms, terminated by imperfect and rounded O faces. A coarse-bladed green hornblende also occurs. Two veins of the pyrite are 3 to 4 inches wide, bunching to a foot and showing rude cubes of pyrite 1 to 1½ inches across, and pyrrhotite in cubical masses up to an inch on a side and in fine crystals an inch long—three-sided, slightly tapering prisms with edges truncated. These crystals weather to a liver-brown; a basal cleavage develops, and the layers warp apart and spoil the crystals.

Albite occurs in druses of many-faced crystals, with beautiful play of color on the $\infty P \infty$ (010) faces. On the dumps everything is coated with a crust of a colorless sulphate.

CLEVELAND AREA.

This is a triangular area 1 mile long from east to west, a half mile wide from north to south, half on the Sheffield quadrangle and half on the Sandisfield quadrangle.

At its northern apex is the Cleveland iron mine, about 100 rods northeast of the house of J. Cleveland. The Becket gneiss, somewhat granitoid, rests nearly horizontally upon the Hinsdale limestone, which is 4 or 5 feet thick, and below this, in the hillside, is a great thickness of the coarse, light-colored Hinsdale gneiss, in which is an irregular vein of magnetite, bunching in places to a foot in width.

The limestone is a white, firm, coarse-grained rock, in most of its thickness showing only a few pale-green mica scales. Some layers are filled with green mica, buff phlogopite, deep-red chondrodite, and colorless tremolite in fine needles.

Commencing about 10 feet below the limestone the gneiss is extensively trenched to open the iron ore. The most abundant variety is a clear gray gneiss, much resembling at first sight the Becket gneiss above the limestone. It is darker gray, firmer, and the black mineral is sometimes wholly black granular hornblende in rounded separate grains with fused surfaces, very different from the same mineral in the black Cambrian gneisses. In other places the black mineral is wholly magnetite. Much of the gneiss is highly stretched, the very scanty dark mineral being a dark-green hornblende, or epidote and hornblende.

Along the magnetite vein the rock is greatly crushed. The purest magnetite is mixed with hornblende, and the folia of the white gneiss inclose rows of large hornblende nodules and masses of epidote and contain druses of albite crystals in cavities.

Coarse, friable, granular limestone, containing many small grains of

dark-green hornblende and pistachio-green pyroxene, are caught up in the crumpled rock (see fig. 11) or intergrown with the white hornblendic gneiss. This is very different in texture and accessories from the compact thick-bedded chondrodite-limestone above. It can best be looked upon as a calcareous vein stone derived from the normal interbedded chondrodite-limestone.

The contact may be seen in the edge of the woods north of the house of J. Canfield, nearly 1 mile southeast of the Cleveland house, just at the west edge of the long bluffs of contorted Becket gneiss which border the road on the north for a long way east of this house. The biotite-gneiss changes suddenly into the coarse hornblendic gneiss. The boundary turns sharply west at this point and must closely follow the road west, as the outcrops of the biotite-gneiss are abundant on the south side of the road past the southern end of the Cleveland road to the vicinity of the Wadsworth mine, 100 rods north and 10° east of the house of Mrs. J. P. Wadsworth. Here are two openings, 10 feet deep, upon a rusting bed of calcareous actinolite-schist. A former limestone bed has been almost wholly changed into balls of a granular grass-green hornblende-biotite mixture. The limestone is pinched into the gneiss in a remarkable way, and where it is changed into hornblende rock it could be mistaken for an altered dike.

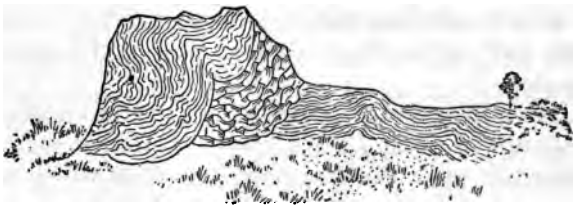


FIG. 11.—Limestone pinched into pre-Cambrian gneiss, Cleveland mine, New Marlboro.

In the center of the area is the Cleveland mine proper—a shaft about 20 feet deep. The rock is a deep-green massive pyroxene-hornblende, carrying much pyrrhotite and a little chalcopyrite, considerable coarse granular calcite, and graphite. The mine was first opened as a gold mine, and I was shown a nugget of gold half as large as a pea and one of silver as large as a dollar, which were said by the owner of the mine to have been obtained from a barrel of the ore (500 pounds). The assay was made by a Boston firm. An assay made by Arno & Co., Cedar street, New York, gave $5.50 gold and $0.75 in silver for 500 pounds. Later assays have shown no precious metals but varying quantities of nickel from 3 to 26 per cent. This information was given me by Mr. Cleveland. The bed was being worked in 1891 by a New York firm as a nickel mine.

The structure of the Cleveland area is anticlinal. The axis is N. 35° W., and the whole is overturned to the west, so that at the northern end, where the overturn is complete, the Becket gneiss rests almost horizontally on the Hinsdale limestone and gneiss. On the southern end they stand almost vertically. Along the southwestern side the

Becket gneiss dips low beneath the older rock and is inverted. Still farther west and lower down the Cheshire quartzite rests on the Stockbridge limestone in the beautiful dome cited by Professor Dana;[1] so that going west from the Cleveland mine one has the whole series, from the pre-Cambrian to the limestone inverted, as indicated by fig. 12, showing section through the Cleveland mine and through Harmon Pond.

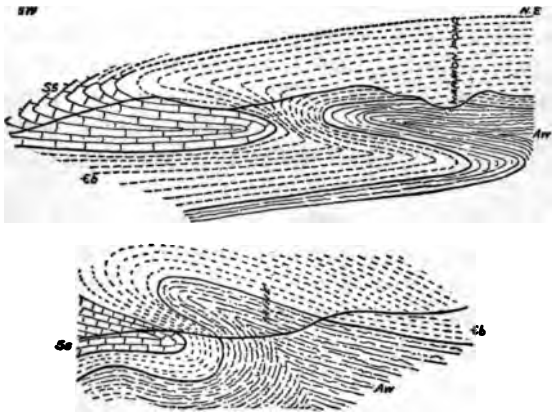


FIG. 12.—Overturned anticline in Cleveland Mountain, west of Harmon Pond, New Marlboro. Cb, Becket gneiss; Aw, Washington gneiss; Ss, Stockbridge limestone.

NORTH CANAAN AND WEST NORFOLK AREAS.

Limestone.—On the road from Norfolk that enters North Canaan at its extreme northeast corner are fine ledges of the white Cambrian gneiss. Crossing the brook and going southwest up the hill we find a small wooded knoll just southeast of the road, which consists of the characteristic schistose nodular gneiss of the region, and shows on its eastern aspect the single outcrop of limestone which is found in the pre-Cambrian of this area.

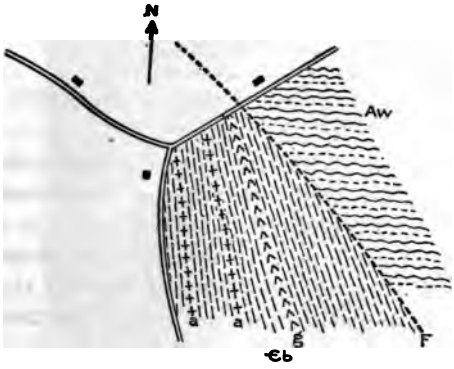


FIG. 13.—Fault contact of pre-Cambrian (Aw) on Cambrian Becket gneiss (Cb) containing granite (g) and amphibolite (a); northwest corner of North Canaan.

It is in the east edge of the woods and 10 rods from the road, and is exposed only 30 feet from north to south and a few feet in width. Prof. William H. Hobbs blasted into it for 8 feet and found it a true outcrop. The limestone dips 50° W. underneath the nodular gneiss, while a few feet to the east the Cambrian gneiss outcrops in the pasture, striking N. 20° E. and dipping 70° W. It is a coarse granular limestone of translucent grains, with rotted chondrodite, phlogopite, and large blue orthoclase nodules.

Nodular gneiss.—The coarse, rusty, highly micaceous muscovite-biotite-gneiss adjacent to the limestone described above is full of large pebble-like nodules, which represent ancient porphyritic feldspars, now

[1] On Taconic Rocks, etc.: Am. Jour. Sci., 3d series, Vol. XXIX, p. 222. (Locality 14 on Dana's map.)

largely changed to matted masses of coarse muscovite which is filled in varying degrees with fibrolite. It also contains large garnets, and weathers to a very rough surface.

The rock contains graphite regularly, and is exactly like the rock of Seymour Mountain in Sandisfield, into which I have traced the pre-Cambrian blue-quartz gneiss of Tyringham and Otis. (See p. 56.)

Following the road a half mile southwest, to near its end on Tobey Hill, we find, south of the red house at the end of the road, the best exposure for the study of these nodular gneisses and their posture against the fault by which they touch the Cambrian on the south (see fig. 13).

The white gneiss (Cb), with beds of amphibolite and garnets, abuts against the nodular gneiss, and this rock continues with a monotonous regularity for a mile southeast, to the west foot of Ball Mountain, where it often carries a little tourmaline.

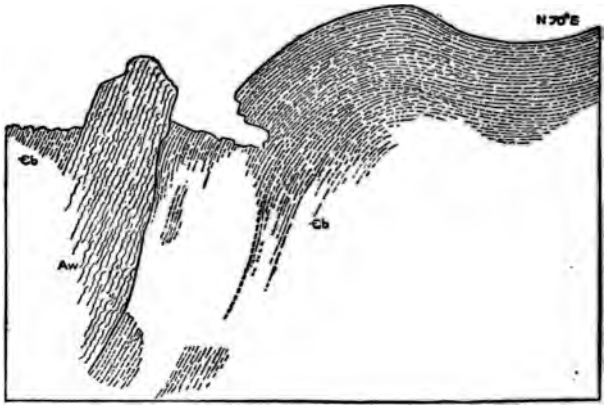


FIG. 14.—Campbell Falls section (central part given in Pl. IV), New Marlboro. Cb, Becket gneiss; Aw, Washington gneiss.

Campbell Falls section.—Following the schistose gneiss a half mile northwest from the limestone, to the point where the next road north crosses Whiting River (the brook coming from East Pond) at a fine waterfall, we find clearly shown the contact of the Cambrian gneiss on the east with the older gneiss. Fig. 14 gives the relations of the two rocks and Pl. IV shows them represented in the central portion of the diagram. All to the right or east of the water is Cambrian gneiss, which continues a little way to the left, to the foot of the vertical bluff of the older nodular gneiss which rises above the upper level of the water. The strong shear planes run in the white gneiss parallel with the falling waters, and west of the pool, at the bottom, the white gneiss can be seen dipping beneath the older rock.

South of the fault the same nodular gneisses appear in force, and one of the best places to study them is south of the road running northwest onto Tobey Hill from the point mapped in fig. 13 (p. 65) and south of the western house in the figure. Specimens from this place have

CAMPBELL FALLS, NEW MARLBORO; LOOKING NORTH.

been described by Professor Hobbs[1] as illustrations of the change of orthoclase to muscovite.

These rocks cross the railroad at the west end of the long West Norfolk cut. (See Pl. V, p. 76.) Here there is first a rusty, spangled muscovite-gneiss, containing graphite, pyrite, and fibrolite, dipping east beneath a light actinolite-garnet-gneiss, which also dips east against a granite-filled fault plane near the third telegraph pole from the entrance of the cut. It abuts against the black quartzite common at the base of the Cambrian.

The same nodular schist makes up the high ground south of the river at West Norfolk and is well represented in the ledges south of the hotel in Norfolk.

On the brow of the hill in West Norfolk, near the south line of the Sandisfield quadrangle, iron ore is found around the house of H. M. Jones, near the upper end of Lake Wungum.

Nodules in the gneiss.—The rock at Campbell Falls is a coarse muscovite-biotite-gneiss, very micaceous, with nodules, about an inch long, of coarse pegmatitic feldspar, bordered by a band of black biotite and brown hornblende. Another form is in its central part made up of a single crystalline grain of quartz, with a partial border of coarse, much-twisted muscovite, both full of fibrolite. Another form is composed of a single large crystalline grain of muscovite, full of fibrolite; and still another is of coarse granular microcline, without fibrolite.

The groundmass of the rock is a finely foliated mixture of muscovite and biotite, often intergrown, often much twisted by pressure and finely foliated, but without fibrolite.

The rock, as found in the ledge west of the limestone on Tobey Hill and in bowlders southeast of Ball Mountain, coming from the same area contains nodules of muscovite full of tufted fibrolite, and large grains of orthoclase also containing fibrolite. The nodules are separated by a finer grained, confused muscovite-biotite groundmass. A quartz-feldspar mosaic often surrounds the nodules, being formed by their partial crushing.

The fibrolite is found in quartz, feldspar, and muscovite, and not in biotite. It is often in a sort of sagenitic network on the C face of the mica, arranged parallel to its prism faces.

Prof. William H. Hobbs has described these nodules from the bowlders and found the cleavage and Carlsbad twinning suture of the feldspar retained in the mica.[1] He gives the following analysis made by Dr. W. F. Hillebrand, of the United States Geological Survey.

[1] Pseudomorphs after feldspar from Norfolk Township, Connecticut: Am. Geologist, Vol. X, p. 46.

Analysis of nodules from Norfolk Township, Connecticut.

	Per cent.
SiO_2	76.32
Al_2O_3	15.87
Fe_2O_3	.53
FeO	.36
CaO	.26
K_2O	4.55
Na_2O	.24
H_2O at 100°	.20
H_2O above 100°	2.01
TiO_2	Trace.
SrO	Trace.
Li_2O	Trace.
P_2O_5	Trace.
Total	100.00

We examined the locality together and then considered the nodules to have been pebbles, as mentioned in his article, an opinion which I have since abandoned.

SOUTHEASTERN AREA.

Above Riverton, on the Farmington River below the Sandisfield quadrangle, is a large outcrop of the Hinsdale limestone and the associated hornblendic and pyroxenic rocks, rising in the center of a broad area which may be associated with the Washington gneiss through the Sandisfield area just described, though the blue quartz is absent, being replaced by fibrolite, while the presence of graphite and of both micas, the rustiness, and the coarse, ragged, somewhat schistose texture of the gneisses distinguish them from the Cambrian above.

A characteristic rock in this area is a dull-black biotite-gneiss, highly fibrolitic and rusty, spangled with large flakes of muscovite and often abounding in large, irregular garnets. The band extends far northeast and southwest, but nearly its full width is found in the Sandisfield quadrangle. Where it enters the quadrangle, east of Mount Pisgah, it is a sugary-crushed, rusty, graphitic hornblende-gneiss.

PYROXENITES AND AMPHIBOLITES.

The passage of the limestone into a coarse-granular leek-green pyroxenite is very common; a large bed of this kind appears at A. Ducharne's, at the south apex of the Sandisfield pre-Cambrian area. (See p. 56.)

A knob of a similar rock projects above the level of the track at the signal house west of the Middlefield station. It is a calcareous diopside rock derived from the pre-Cambrian limestone and projecting into the Becket gneiss. Other similar projections appear in the cut nearer the limestone. It has disseminated crystals of a black hornblende, luster-mottled (poikilitic) by the earlier diopside, and changes into a green amphibolite which contains little plagioclase and no ore.

Because of the interest which attaches to *the origin of amphibolites,* special attention is called to the change of the limestone in Hinsdale into black, massive amphibolite and hornblendic gneiss, both by the formation of interstratified beds of various dimensions, and by an alteration progressing from both the top and the bottom until only a few feet of limestone remain at the center, and also to the Cleveland area, where the limestone is pinched into the gneiss like a dike and then partly changed to amphibolite (fig. 11).

The amphibolite which occurs in continuation of the limestone at the Alderman farm at Becket Center and which has been quarried as emery and copper ore, and the exactly similar rock found adjacent to the Coles Brook limestone 1 mile east of the Alderman farm, are more difficult of assignment. This is a black, massive, granular rock quite like the altered Cambrian dikes described below. It carries garnet, and the black ore which it contains is associated with titanite (leucoxene); the colorless ground is largely quartz. The rock is much like the Lee gneiss above East Lee, described on page 33, and I have associated it with the Lee gneiss, as a derivative of the calcareous transition beds above the Hinsdale limestone.

ANALYSES OF PRE-CAMBRIAN LIMESTONES.

The following analyses of pre-Cambrian limestones are taken from Hitchcock's Final Report of the Geology of Massachusetts, page 80. The other Berkshire analyses in this table are of the Stockbridge limestone:

Analyses of pre-Cambrian limestones.

	1.	2.	3.	4.
$CaCO_3$	54.80	56.25	51.66	58.31
$MgCO_3$	44.98	31.56	39.48	28.61
Fe_2O_3	.22	1.12	.91	1.24
Impurities	.....	11.07	7.96	11.84
Total	100.00	100.00	100.01	100.00
Sp. gr.	2.77	2.78	2.77	2.84

1. Lee, 1 mile east of village; burned for lime. This is from the hill above East Lee.

2. Middlefield; Coles Brook; white.

3. Blandford; white. This is a great bowlder from the Coles Brook bed, found south of the village of North Blandford.

4. Becket, southeast part; magnesian.

CAMBRIAN SYSTEM.

An inspection of the map will show that the Cambrian gneisses and quartzites cover more of the surface than do the rocks of any other system.

In the area between the pre-Cambrian and the Stockbridge limestone it is helpful to carry out the distinction between the lower portion of the system—the Becket gneiss, which was originally largely conglomeratic and is now chiefly a muscovite-gneiss with some quartzite—and an

upper portion which was originally largely a quartz sand and is now changed to a more or less micaceous quartzite—the Cheshire quartzite, very generally characterized by the presence of minute crystals of dark-brown tourmaline, although the quartzite sometimes extends to the base of the system.

This quartzite is locally replaced by a mica-schist, which is often greatly corrugated. On the east side of the pre-Cambrian the Cambrian is largely a biotite-gneiss and is completely gneissoid up to the hydromica-schists and lacking in tourmaline.

UNCONFORMITY AT THE BASE OF THE CAMBRIAN CONGLOMERATE.

Five rods east from the mountain cottage on the hill high above Dalton Station the conglomerates, themselves nearly horizontal, can be seen resting upon the vertical beds of the older gneisses which strike N. 80° E. One can follow the junction in the cliffs south and then for a mile southwest down the mountain side, to the brook above J. S. Barton's, with excellent exposure, as indicated in fig. 4, page 40. It continues up the side of Warner (or Day) Mountain, and on south through the woods for 2 miles to the great fault described hereafter (p. 92). On the opposite side of the anticline, along the east slope of the same hill, the same unconformity can be seen, though the outcrops are poorer. Everywhere the old gneisses strike N. 80° E. and are nearly or quite vertical, while the conglomerates, nearly horizontal at the top, take a low dip westward down the west side and eastward down the east side of the long hill, and before it was cut through along the crest of the hill they mounted over it symmetrically.

The unconformity is thus striking, abundantly exposed, and extends for a long distance. The same unconformity clearly exists along the west flank of the West Washington anticline (shown well at P. Conroy's house), a mile northwest of the Becket reservoir.

Around the great Hinsdale anticline there is everywhere a general apparent conformity, but there is very commonly a discrepancy of 10° to 30° in the strike, while the dips uniformly agree in being low to the east; but the whole anticline is so forcibly pushed over westwardly and flattened, and the outcrops on the exact junction are so few, that it gives little important evidence on the subject.

The pre Cambrian at the Coles Brook anticline is thrust very irregularly through the Cambrian, and the unconformity is well shown in the description of the section at the mouth of the brook (see p. 41), and is apparent in the whole length of the band from the contact of the Cambrian gneisses with the different members of the older series. It is more beautifully shown a mile north of the railroad cutting, where the road comes down off the mountain and crosses the limestone near the site of the burned house of H. Hawes. As seen in the figure (fig. 15), the Cambrian gneiss wraps in easy folds over the vertical pre-Cambrian limestone, which is accompanied by a rusty biotite-muscovite-

gneiss, with tourmaline and coarse graphite, and on the top of the hill, where the gneiss is worn through, the limestone appears.

A nearly vertical secondary schistose structure is present in much of the gneiss. It is a typical Becket gneiss, with many striated octahedra of magnetite, and at the sharp bend in the road it contains an 8-foot bed of a fissile black amphibolite with films of biotite. This makes a very beautiful slide under the microscope. Around the many grains of magnetite an abundant growth of titanite (leucoxene) appears, swelling into larger crystals in a limpid ground of untwinned plagioclase grains. It is probably an altered eruptive rock.

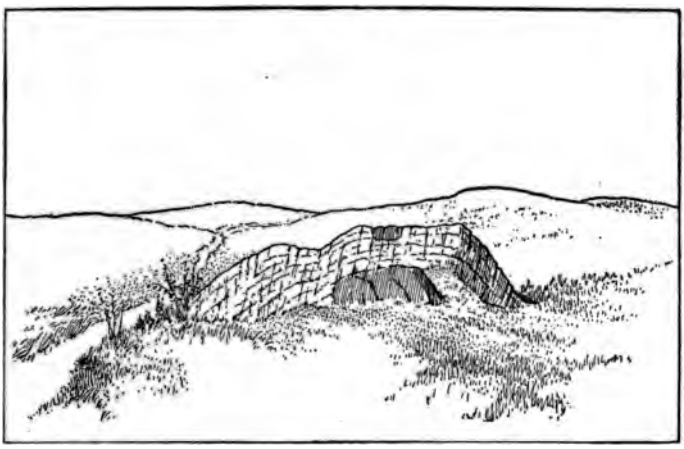


FIG. 15.—Cambrian gneiss folding over pre-Cambrian limestone unconformably; Middlefield.

CONGLOMERATE-GNEISS (BECKET GNEISS).

In the northwestern part of the area the broad band of light-colored gneisses which encircle the old blue-quartz gneiss of the Dalton anticline is as uniformly characterized by the abundance of muscovite as the older series is by that of biotite. The latter mineral is not always absent in the newer rock, but when it does occur it is in small, scattered flakes, not in connected films.

All the other characteristics of the older series are conspicuously absent, except that the blue quartz occurs in grains and pebbles, plainly secondary. It passes gradually upward into the Cheshire tourmaline-bearing quartzite.

The base of these gneisses is often a heavy bed of the most clearly developed conglomerate of quartz pebbles—white, black, and blue, commonly white, with rarely a pebble of feldspar or gneiss—from 5 mm. to 100 mm. in length, uniformly well rounded, and all arranged parallel to a common plane. They are sometimes apparently flattened parallel to that plane to quite broad sheets, in one case to round-edged plates of quartz 150 mm. by 100 mm. by 10 mm. These pebbles are generally inclosed in a large quantity of groundmass, which is changed into a

rock then weathers white. After rains they accumulate by the roadside as iron sands.

One or two bands of a jet-black, fine-grained biotite-hornblende-gneiss occur about one-fourth of a mile east of the boundary with the older rocks. There is rarely any trace of pebbles in the gneiss along the boundary or elsewhere.

The amount of quarry gneiss is inexhaustible, and the rock from the large quarry on Ball Mountain, Norfolk, can not be distinguished from the Becket and Monson quarry rock. In Otis the white gneiss branches on the pre-Cambrian, and its western lobe runs down west of Filley Mountain to the Tyringham fault, while its border portion continues down the eastern part of the quadrangle inclosing Great Pond and the Otis reservoir. It is a very uniform biotite-gneiss. The jet-black biotite is generally disseminated through the rock, at times concentrated in rounded or elongated blotches or in distinct banding. It generally bleaches at the surface to a dead white, but always contains much magnetite in minute octahedra. At times it is strongly muscovitic, as where the East Granville road crosses the east line of the quadrangle, and at the northeast slope of Noyes Mountain. Where it enters the Sandisfield quadrangle it is largely garnetiferous, but this characteristic disappears to the south. Only one small hornblendic bed occurs in it. This is east of D. Goddard's, a mile east of Otis Center.

Considerable excavation for iron has been made west of T. Fay's, a mile farther east, beginning more than fifty years ago. The gray gneiss is here a little more impregnated with magnetite than usual and carries hornblende.

In Otis the rock generally occurs in smooth, white ledges, with a fine-grained granitoid structure, very free from fissures, and breaking in large blocks, or, while breaking in equally large and firm blocks, showing a flat or wavy contorted banding from the arrangement of the biotite. It at times weathers into a ragged and deeply pitted and seamed rock, as in the remarkable bare ledge which starts from the southeast lobe of Otis reservoir and runs over the top of Noyes Mountain, a famous fox run. It nowhere shows any trace of conglomerate structure, and I have at times tried to refer portions of it to a certain wholly crushed facies of the Washington gneiss, but on comparison, especially under the microscope, it seemed plainly not to belong to that type. The Becket gneiss at its junction with the pre-Cambrian across Sandisfield and Tolland has been quite fully described in tracing the upper boundary of the latter (see p. 55) from the apex of this South Sandisfield lobe, to the north of which it is greatly corrugated, around to that village. Typical quartzite and a black pyritous quartzite accompany the boundary and lie well down toward the base of the Cambrian, where the rock is usually gneissoid, so that in the southern part of this area I have not tried to carry out the distinction between the basal gneiss and the quartzite above, which is so well developed in

the Becket region. All across Sandisfield the Becket gneiss is very generally a fine-grained, gray, quarry gneiss, of good quality for building purposes.

AMPHIBOLITES IN BECKET GNEISS.

On page 68 reference is made to pyroxenites and amphibolites derived from pre Cambrian limestones.

East of the Connecticut the Becket gneiss is often black, from excess of the shining black biotite and fine granular hornblende, assuming the aspect and relations of a crystalline schist, and seeming to have the same origin as the conglomerate-gneiss itself, into which it passes and of which it is, in my opinion, a mere ferruginous and calcareous variant.

In tracing the Becket gneiss of the western region south from Hoosac Mountain I did not find any hornblendic beds until the locality at H. Hawes's, in Middlefield (see p. 70), and the Chester Company's quarry in Becket were reached.

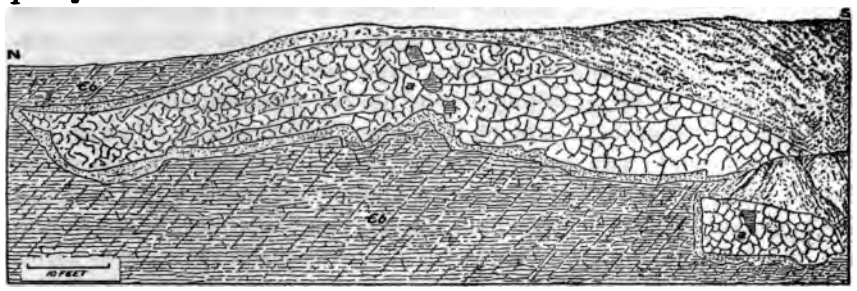


FIG. 16.—Amphibolite dike (a) in white granitoid Becket gneiss (Cb) with pegmatite contact rim (p); quarry, Becket.

At the latter place a great mass of a fine, jet-black, massive and friable biotite-amphibolite extends, with a width of 12 to 15 feet, across the east wall of the great quarry (see fig. 16). It tapers to a point at the north end, and a separate or faulted portion of the main dike appears at the south end. It contains blocks of the white gneiss and, what is very peculiar, is separated from the inclosing white, massive biotite-gneiss by a quite continuous band of a coarse muscovite granite or pegmatite a foot wide, a phenomenon which is repeated several times farther south, as at the Ball Mountain quarry and at the West Norfolk cut.

Under the microscope the rock shows in a fresh, limpid ground of granular quartz and plagioclase-feldspar (the latter gave in plates parallel to M, the optical figure of oligoclase), and abundant grains of hornblende, biotite, and magnetite. In many of the occurrences farther south the grains of each mineral have nearly a common size, giving the slide a very regular look. Here many smaller flakes of the same minerals are inclosed in the feldspars.

Some of the black ore grains are surrounded by titanite (leucoxene). It is not, however, nearly so abundant as in the Middlefield bed described on page 70. Titanite generally characterizes the amphibolites

in the Cambrian beds, which I have considered to be derived from gabbros or diabases, and is absent in the similar beds which I have supposed to be altered calcareous deposits.

From this point on, going south, the hornblendic beds grow more abundant in the white gneiss and come to be quite characteristic of the basal beds of the Cambrian near the contact with the underlying pre-Cambrian. This is so uniformly the case in the region surrounding the Bear Mountain anticline that it gives a safe indication of the position of the boundary where it is concealed. The beds are generally without structural indications of eruptive origin, are often more biotitic than hornblendic, and, as they are always interbedded with the gneisses, have probably had a similar sedimentary origin. They are too small to be represented on the map.

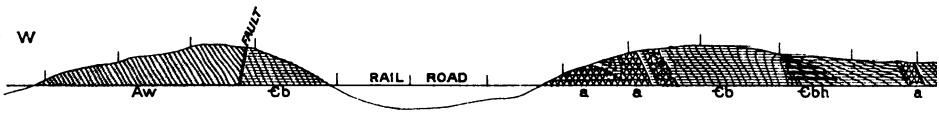
The hornblendic rocks are even more abundant in Norfolk, and both the sedimentary and the intrusive kinds are represented. Haystack Mountain, Ball Mountain, and the high hill to the east are largely composed of amphibolite and seem to owe their height to its durability. In the quarry on the east face of Ball Mountain is a black dike exactly like the Becket dike previously mentioned. The country rock is the granitoid white Becket muscovite biotite-gneiss. It contains inclusions of a black rock much like the dike. The dike is wholly inclosed in the gneiss, is 8 feet wide, and extends 5 rods south before being covered. It is cut by a dike of pegmatite a foot wide—a clear, gray rock with idiomorphic quartz, much plagioclase, and shining, black biotite which is coarser than the biotite of the gneiss.

The rock is the same black granular rock, suggesting fine-granular tourmaline, but slides cut from different parts of the mass vary materially, while the hornblende and the black ore surrounded by titanite are the same. In one slide the biotite is of even size with the hornblende grains and free from inclusions, and the abundant colorless ground is largely granular quartz; in the other slide the large porphyritic biotite scales inclose all constituents except hornblende, and the ground is a fresh, granular, mostly untwinned feldspar, with the border of each grain differing sharply from the center.

The whole top and west slope of Ball Mountain are composed of the same black, massive, hornblende-biotite rock.

In the southeast wall of Ball Mountain the light-gray gneiss wraps round the rectangular south end of the black, massive amphibolite exactly as if that had been a more massive foreign body in the conglomerate-gneiss at the time of the folding. This is like a diabase dike, but it is also like a displaced limestone bed, and either one may be changed into an amphibolite. (See p. 64.)

Haystack Mountain, on the contrary, is made up of a highly contorted hornblendic gneiss, generally biotitic, pyritous, or garnetiferous, thin foliated and carrying intervening thin bands of a white gneiss a foot or so in width, which look like dikes in the black rock.



SECTION ON R.R

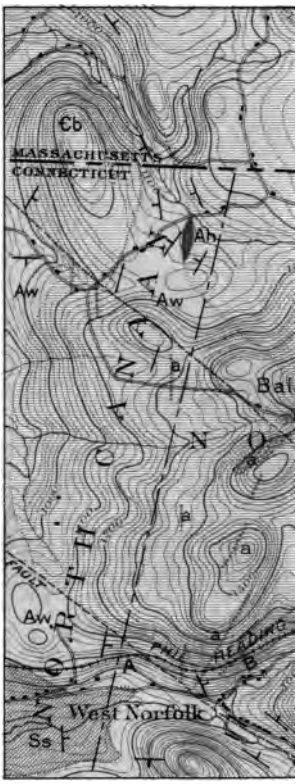
Sca

100 0 100

DETAIL AT 1 ON SECTION

Scale

1 FOOT



Sca

1 0

LEGE

SILURIAN | CAMBRIAN | PRE-CAM

Ss — Stockbridge limestone

Cb — Becket gneiss

Cbh — Hornblende-schist

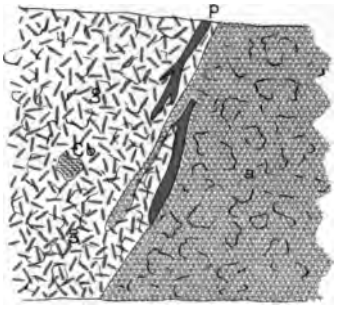
Aw — Washington gneiss

NORFOLK RAILROAD CUT AND MAP

T A-B ON MAP

0 300 400 FEET

2 MILES



DETAIL AT 2 ON SECTION
Scale
10 FEET

ID
RIAN

ERUPTIVE

linsdale limestone | Pegmatite | White granite | Amphibolite

HOWING LOCATION, WITH DETAILS.

A. Hoen & Co. Lith. Baltimore.

The great railroad cut west of West Norfolk Station shows all the relations of these rocks to the best advantage. It is illustrated by the section on Pl. V. Entering the cut from the west the rusty pre-Cambrian gneisses (Aw) occupy the first 28 rods. At first they are granitoid and carry graphite. They are succeeded by light actinolite-gneisses carrying garnet. Both minerals are indicative of the near presence of limestone in the rock. These are all characteristic pre-Cambrian peculiarities. Then comes a fault marked by a pegmatite (p) layer, and this is followed by the light biotite-gneisses (Cb), which carry near the base a heavy band of thin-bedded micaceous quartzite.

On passing an interruption in the cut we again come to the same gneisses, in which is a great dike-like mass of amphibolite (a), or what may be taken to be a wholly altered basic eruptive.

This is immediately followed by another entirely similar bed, which includes great masses of the gneiss and has a sharp but irregular boundary against the inclosing hornblende-gneiss (Cbh), which latter, from the analogy of the similar bed described below, seems to be older than the two dikes described above and to be of sedimentary origin. Then follows the foliated and finely twisted amphibolite bed (at 1 in the section), which is given in detail on Pl. V. The contorted foliation of the inclosing schist runs parallel with the walls of the black bed; and both are partially sheared asunder and quartz veins occupy the distant shear planes.

Near the east end of the cut is a broad bed of a fine-grained white granite (g), which on the east abuts against the foliated amphibolite (at 2; see detail figure) and includes great angular blocks of it, together with the common gneiss, thus showing that both these rocks are older than the granite. At the east end this granite is cut by two dikes of the black massive amphibolite, into which it sends tongues, thus showing that this massive amphibolite is newer than the foliated amphibolite. The granite has produced a marked metamorphic effect upon the black rock. An outer layer of the latter a half inch wide has lost its banding and is of much coarser grain.

In both cases a selvage of pegmatite separates the amphibolite from the white granite. These foliated amphibolites lack some of the peculiarities of the amphibolites derived from eruptives and resemble those derived from limestone described on page 69.

The two dikes just mentioned share all the properties of those described above from near the west end of the cut, but differ considerably in minor matters.

The dike, with inclosures, at the twenty-first telegraph pole from the west end of the cut is the normal type of the Cambrian eruptive amphibolites or metadiabases. It is a blackish gray, massive, fine-grained rock, made of shining hornblende needles, biotite scales, and a small amount of white interstitial matter just visible to the eye.

Under the microscope plagioclase appears, rarely twinned and with

small angle of extinction. Many large grains, which seem exactly like quartz, are biaxial and positive, and so are plagioclase. The hornblende is in jagged angular cuboidal grains, with strong absorption and deep colors—*a*, bright yellow; *b*, yellow to greenish yellow; *c*, blue green; $b>c>a$ Ex. 23°—29°. Menaccanite occurs and leucoxene is abundant.

The garnet-amphibolite from the dike at the east end of the railroad cut is with the lens not distinguishable from the other metadiabases of the region. It is a massive, fresh-black, fine-grained rock, mostly black granular hornblende and white granular plagioclase.

Under the microscope it is quite peculiar. The hornblende has rather less absorption and is composed of large aggregations of small scales, sometimes polarizing together and grading into large grains which are centrally filled with large needles placed parallel to the cleavage.

The garnet grains are free from inclosures and are surrounded by a beautiful radiated aggregate of plagioclase blades which expels all the colored constituents and has exactly the aspect of the secondary water-deposited albite filling cavities in the Triassic diabase from Greenfield.[1] The resemblance is so exact that one may feel sure that this limpid plagioclase is also water deposited. The plagioclase molds the garnet grains and radiates from them. The two minerals occupy angular spaces, as if they replaced a porphyritic mineral.

The magnetite is surrounded by a very ferruginous biotite, but never by titanite (leucoxene). There is a little quartz present.

CHESHIRE QUARTZITE.

The basal conglomerate of the Cambrian originally passed up into a sandstone which is now represented by a white quartzite, often largely muscovitic, always deficient in feldspar, and quite regularly characterized by small black or dark-brown tourmalines. It is at times simply a white friable quartz-sandstone, often dug for glass making; at times a thin fissile muscovite-quartzite, which can be seen to change along the strike into muscovite-schists or white gneiss; and at times a tough, massive quartzite.

In the high ground north of Dalton village the quartzites are present in great force, are at times calcareous and at times muscovitic, but are not developed as distinct gneisses upon the Becket quadrangle. They are hard, massive quartzites where crossed by the roads. At the southwestern corner of the high ground, as represented on the map, they are white, sugary, glass sands, which were entered to a depth of 180 feet in digging for a well on Mr. Thomas Allen's farm, Grasmere, just south of Coltsville Station.

They are at times metamorphosed into distinct gneisses. Of such a character is the fine long exposure in the railroad cutting which extends from the railroad crossing of the Hinsdale-Dalton road, near the Cath-

[1] Bull. Geol. Soc. Am., Vol. VIII, 1897, p. 59.

ville cemetery, north to the line between those towns. *The beds sweep* in a broad curve, with strike northeast to northwest, and represent the center of the overturned syncline between the two anticlines, and thus the top of the series.

The rock is a muscovite-schist, at times a sericite-schist, highly contorted. It dips eastward, as forming the east flank of the Dalton anticline; and entirely similar but less altered beds occupy the other (western) slope of Warner Hill, dipping westwardly on the other slope of the anticline. Here, in the brook bed above J. S. Barton's, the rocks above the conglomerates are white mica-gneisses or quartzites, and certain beds are a pure quartzite full of quite large drusy cavities, now partly filled with kaolin from the alteration of feldspar. The rock rarely contains small tourmalines and magnetites.

The metamorphosis of these beds plainly decreases toward the north and west in the region under discussion, so that the minimum of change appears in the northwest corner, on the brook last mentioned.

The quartzite along the west slope of the Dalton anticline is very thin bedded, and the greatly corrugated and discordant layer of the mica-schists upon it makes it probable that part of its thickness may be concealed by a fault.

South of the South Dalton fault, on the high ground southeast of Pittsfield, the quartzite widens into a broad area. It lies nearly horizontally and rises eastwardly in soft undulations. Where the Pittsfield-Washington road crosses the corner of Dalton and makes a large bend to the east the rock carries so much muscovite that it deserves the name of a schist, but it does not approach in type the higher schists and has all the characteristics of the quartzites (tourmaline, sandy structure). The same is true on the next road south, south of S. Hines's, where mica-schist is shown on Professor Dana's map. These quartzites pass around the north end of the Washington anticline in a broad flat syncline in the conglomerate-gneiss, which extends far out over the high ground in a very unusual position for such soft and slightly metamorphosed rocks. Just where they are cut by the line of latitude 42° 25′ they overhang Sackett Brook in bluffs more than 100 feet high.

They are dug as glass sands at the extreme southeast end of this syncline south of Ashley Lake, in the middle of Washington. They are everywhere characterized by fine tourmaline needles and are generally muscovitic in greater or less degree.

KAOLIN FROM THE QUARTZITE.

Professor Dana has called attention to the decay of the quartzite south of Ashley Lake, in Washington, and to the formation of sand therefrom, and explains this decay as due to the decomposition of the feldspar in the feldspathic portions of the sandstone.

The quartzite, which varies from the hardest to the most friable and

from massive to thin bedded, has at times quartzose layers alternating with thin seams of soft kaolinized feldspar.

Many kaolin beds of western New England occur in quartzite, and are washed out from the decomposed quartzite. This is true of the largest of these deposits, that in the southwest corner of New Marlboro, near the Canaan boundary. The kaolin is sandy and contains quartzite fragments.

Feldspathic quartzite occurs near the line between Lenox and Washington. Large cavernous blocks lie over the fields, with cavities an inch or more long.

Dr. C. Dewey says it is wrought into millstones after the manner of the Paris buhrstones, and is known as the Pittsfield buhrstone.[1]

Feldspar still exists in some of the cavities. Prof. E. Hitchcock recognizes the feldspathic character of the rock in his Massachusetts Geological Report of 1842, saying (page 587) that the buhrstone is "a variety of gneiss rock whose feldspar has decomposed and disappeared, and in which quartz was greatly the predominant ingredient." The name "gneiss," which has been given it, is not so far out of the way as might at first seem, for some of the rock contains, besides feldspar and quartz, a little mica.

The hearthstone quartzite quarried less than a half mile south of this locality, which affords the best hearthstones of western New England, contains black mica, in very minute scales disseminated through it, like much of the quartzite elsewhere.

Professor Hitchcock mentions another locality, 4 or 5 miles south of the spot where millstones are prepared, at which the rock "may be seen in all stages of the process between gneiss and buhrstone."[2]

QUARTZITE BRECCIA.

I have mentioned the breccia found along the South Dalton fault. The massive quartzite is shattered, the fragments being often moved on one another and cemented by limonite. It was first described by Dr. Chester Dewey in 1824,[3] and is mentioned by President Hitchcock in his report of 1841 (p. 588). He enumerates it in his catalogue of the State collection in 1841 (Nos. 604–606) and 1856 (quartzite, Nos. 59, 60, and 107, 108) as brecciated quartz; cement hematite. It is attributed by Professor Dana to the wedging open of the fragments by "the extremely slow action of the depositing limonite."[4]

I have found it so closely associated with faults that I have no doubt that it is a fault breccia, produced by friction along the great transverse faults, the fragments being afterwards cemented by infiltrating iron solutions at so low a temperature that the cement is limonite.

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[1] Am. Jour. Sci., 1st series, Vol. VIII, p. 17.

[2] J. D. Dana: Am. Jour. Sci., 3d series, Vol. XXVIII, p. 448.

[3] Am. Jour. Sci., 1st series, Vol. VIII, p. 18.

[4] Pseudobreccia, by J. D. Dana: Am. Jour. Sci., 2d series; Vol. XXVIII, p. 451; Vol. XXIX, p. 57.

TRANSITION OF LIMESTONE INTO SANDSTONE.

In the single spur which projects into Lake Garfield, in Monterey, from the middle of its southern shore is a ridge of the white limestone resting upon a highly calcareous sandstone and dipping 50° S.

At the south end of the Monterey pre-Cambrian (see p. 60), south of the brook opposite the E. R. Smith place, the pure white limestone is full of white pyroxene crystals and quartz veins and grades into a rusty biotite-schist. It is sandy in some places and black and flinty in others.

A few rods north of the village of New Marlboro, and west of the north road, is a white, friable, micaceous sandstone, which is pounded to a white sand by the feet of cattle. It is very calcareous and lies almost horizontal in the Becket gneiss, into which it passes.

Along the south slope of Dry Hill, northwest of New Marlboro, 80 rods northwest of D. S. Powell's house, is a row of outcrops, 125 rods long, of the Stockbridge limestone, resting as a thin layer upon the banded micaceous quartzite. It wraps round projections of the schist, dipping away from them on all sides, and passes gradually into the schists below.

SILURIAN SYSTEM.

HOOSAC SCHISTS.

Windsor mica-schist bed.—The anticlines of pre-Cambrian gneiss along the eastern side of Berkshire County are flanked east and west by light-colored conglomerate-gneisses, and these are followed on the east side by a series of mica-schists, at first garnetiferous, then feldspathetic (porphyritic), and still higher up sericitic.

The careful studies of Professor Wolff[1] have traced these schists around the north end of the Hoosac anticline and down its western flank to where they run out onto the gneiss as a narrow band which finally disappears just northwest of Savoy Hollow. In this passage out onto the gneiss the mica-schist lies in a syncline in the gneiss running southwardly, and it is probable that the mica-schist described below is the continuation of the same bed.

The boundaries of the bed can be rudely defined by bowlders west of Windsor Hill, nearly 3 miles south of the above-mentioned terminus of the Hoosac schists in Savoy, and abundant outcrops of the rock soon appear and continue in a high, narrow ridge to the Hinsdale line, just east of the reservoir.

It can be best studied at A. W. Warren's. It seems to lie in a westwardly overturned syncline in the Cheshire quartzite, which lies in the newer gneiss, but with only a narrow seam of the latter separating it from the old pre Cambrian graphite-gneiss.

It strikes N. 10° to 20° E. and has high dips to the east, but is for the

[1] Mon. U. S. Geol. Survey, Vol. XXIII, p. 80.

most part so twisted and contorted that no prevailing directions appear. It is a coarse, black, garnetiferous mica-(biotite) schist, highly graphitic or coaly, causing the black color. The garnets are of the form 110 and small. Quartz veins with sulphides occur.

Coltsville mica-schist bed.—The whole hill east of and overlooking Coltsville and forming the western foothill of Davis Hill, northeast of Dalton, is composed of a dark lead-gray mica-schist or phyllite, greatly contorted and abounding in fine quartz veins with large quartz nodules which look like pebbles. The rock is plainly graphitic and contains a few garnets. It dips southeast beneath limestone.

Dalton bed.—Following west down Barton Brook, on the west slope of Day Mountain, from the contact of the older gneiss and the conglomerate-gneiss at the clubhouse (see fig. 4, p. 40), one passes over the whole of the latter and a great thickness of the white quartzite-gneiss lying stratigraphically above the conglomerate, all having a strike N. 40° E. and dipping 30° W. beneath another bed of these schists. The nearest outcrops of the quartzite to the schist are at the road-crossing of the next brook south, so that only a small thickness of intervening strata remains concealed.

The schists are here greatly contorted, strike irregularly N. 70° E., have high dips to the west, and are plainly discordant to the gneisses below.

These schists advance westwardly to the railroad, and at the foot of its embankment runs the Housatonic River. At the Carson & Brown Company's paper mill on this stream, just opposite the schist, the boring of an artesian well went down 135 feet through limestone containing a 20-foot bed of quartzite, and at that depth the drill dropped 3 feet, in a water seam said to have been full of worn pebbles, onto a surface of the same black schists, in which the boring was continued 9 feet. I have compared fragments of the schist from this boring with the adjacent ledges and they are identical. This brings these schists into the same position as the schists previously mentioned at Savoy and Windsor. On the other hand, these Dalton schists differ from the schists which succeed the white gneisses on the east in Middlefield and Becket.

Mica-schist of Dry Hill in New Marlboro.—The mica-schist which wraps around the quartzite of Dry Hill in New Marlboro and grades into the Stockbridge limestone occupies precisely the same stratigraphical position as the Dalton schist. It is composed of thin bands of a white, sugary quartzite, one-fourth of an inch to 1 inch wide, with equally thick intervening layers which are quite micaceous. The mica is fine grained and generally muscovite, though sometimes much biotite is present. High up the hillside the rock is a dark mica-schist, its dark color due to excess of biotite and hornblende.

Eastern band.—At the base of this formation a dark, highly garnetiferous mica-schist forms the passage bed from the Becket gneiss to the *main portion* of the series.

The latter has the habit of a mica-schist, although it is generally quite feldspathic. Small rounded crystals of albite, scattered porphyritically in the mass, have in crystallizing often cemented several grains of quartz together.

Both micas are present and the rock is generally quite dark, from the abundant biotite. It shares with the following formation the greasy feel from the hydration of its muscovite.

The base of the bed is exposed on the road lying east of Peru Center, at D. E. Ingalls's, the second house to the south after leaving the village. It is here a coarse and corrugated feldspathic mica-schist, full of garnets as large as raisins.

Two miles northwest of Peru Hill, at the stone schoolhouse, the upper boundary of the Hoosac schist upon the Rowe schist is exposed for a long distance on the bare hill 50 rods east of the schoolhouse. The rock is a gray porphyritic gneiss—a rock with the habit of a coarse sericite-schist but abundantly porphyritic and with small oval spots of white feldspar. It is well exposed east of Bancroft station on the Boston and Albany Road, beginning with the mouth of Factory Brook and extending a half mile east. At the base it is a coarse sericite-schist, full of garnets one-third of an inch across, and the same bed extends north to Middlefield Center and beyond. In the upper part the garnets are absent, and sandy layers alternate with the more micaceous bands. This continues to the bridge east of the station.

The next accessible section of the series is along the road west from Chester station, just within the limits of Becket. Where, at the southeast corner of the Becket quadrangle, the road goes south from Walker Brook to the Chester Company's quarry the brook cuts a contorted, light-gray, thin-bedded biotite-gneiss, with layers two-thirds of an inch thick, strike N. 15° W., dip 70° E. It has muscovite on foliation faces and much of it is soaked with pegmatite.

A little east, halfway to the next house, a highly muscovitic saccharoidal gneiss is kneaded in with a highly garnetiferous, rusty mica-schist, of quite coarse grain, which forms the basal layer of the terrane under discussion. Strong, coarse mica-schists follow, mainly coarse films of muscovite scales and an arenaceous quartz ground with no bands or nodules of infiltrated quartz, few garnets, and rarely blotches with feldspar aggregates. A thin section of the rock from the east of Becket (E. B. Richards's) shows a gray, rusty, muscovitic gneiss; raveled and ragged intergrowths of muscovite and biotite and a mosaic of quartz grains wrap round porphyritic "augen" of albite, which in places shows extinction according to two laws and the granophyric structure in every variety and of great beauty. The garnets are centrally filled with brightly polarizing black rods and long blades of biotite.

ROWE SCHIST.

Only a narrow band of the Rowe schist runs down the eastern border of the sheet for half its length. The small porphyritic albites disappear and the rock becomes a softer sericite-schist blotched with green, due to chlorite spots derived from altered garnets. Going east from Bancroft station to the third bridge one finds the boundary and a sudden transition from the albitic schist below. Along the railroad two bands of amphibolite occur in this formation before the edge of the quadrangle is reached. Along the east line of Becket, east of the Chester Company's quarries, it contains a gray cyanite, which includes small garnets with the centers filled with black grains. The cyanite is often changing into muscovite. (See Pl. I, fig. 6.)

Where the schist enters the Sandisfield quadrangle it is a hard, ragged, contorted muscovite-biotite-schist barren of accessories, slightly rusty and quartz veined; the zigzagged bedding goes N. 40° W., the cleavage N. 50° W. Higher up it has small hornblende-schist layers and is in places garnetiferous and of greasy feel.

STOCKBRIDGE LIMESTONE.

Only a narrow portion of the white crystalline limestone which underlies and has conditioned the broad Housatonic Valley, enters the area on its western borders and extends far east into broad depressions in the older rocks in Dalton and Tyringham and into smaller recesses south of the fault on the south line of Dalton and at East Lee. Its boundary is thus for 10 miles a straight line parallel with and near the western edge of the Becket quadrangle, while the broad sands of the Housatonic conceal nearly every portion of the limestone in the low valley bottom.

The scarp of the older rocks, which looks down on the limestone valley, is offset to the west in Bear Mountain, and on the southern half of the area the eastern boundary of the valley limestone lies far west of the territory covered by the map. The rock also extends eastward in a great lobe far out over the highlands in Monterey, and two smaller lobes enter the area at New Marlboro and at West Norfolk. In its northern portion it is mainly a calcareous carbonate and is for the most part free from accessory minerals. I have collected rutile and brown tourmaline in the quarry at Coltsville. It is a white-to-gray marble, everywhere quarried locally and furnishing good building stone in inexhaustible quantity, so that the location of quarries is mainly dependent upon the proximity to railroads. Much has been written about a flexible variety of the marble (see Calcite in lexicon, p. 107) occurring near Pittsfield.

Farther south the extensive quarries at Lee are within the limits of the area considered, and from these quarries much marble has been shipped to Washington, Philadelphia, New York, and Albany. Here some beds of the rock are filled with a white-bladed tremolite, which is *represented* in every mineral cabinet.

This limestone is thickly covered in the bottom of the Tyringham

U. S. GEOLOGICAL SURVEY

HYDES FALLS.

Valley. For a long distance north of the fault it is absent, and in this distance the springs and wells on the north of the fault give soft water and those on the south of the fault give hard water. At Mr. D. Clark's and eastward the limestone is preserved on both sides of the fault, but is very thin. All the springs are of soft water.

The limestone that runs horizontally high up on the south side of the Tyringham Valley at Fernside is the common, gray, barren Stockbridge marble. On the hillside across the strike the pure limestones grade into gneiss, through a large series of calcareous schists, often very rusty. The series is thus inverted and is the upper limb of a small fold overturned to the north, its axial plane dipping south into the mountain.

On the other side of Bear Mountain the limestones dip northeast into the mountain; they can not go under it, as its nucleus is pre-Cambrian. There is thus some form of fan structure present here, as was suggested to me by Prof. T. Nelson Dale. (See section on the Bear anticline, p. 58.)

The Monterey limestone grades in every direction into a sugary calcareous quartzite, and this, with the exceptionally heavy cover of till, makes it impossible to put accurate boundaries on the map. At the branch in the road south of the outlet of Lake Garfield is a broad area of a white, sugary limestone with much white pyroxene overlain by a rusty jointed. black, pyritous quartzite. The accompanying plate (Pl. VI) shows a beautiful anticline in this limestone at Hydes Falls, 1½ miles south of Monterey.

Farther south other remnants of the marble exist on the surface northwest of New Marlboro, and several instances of its passage into the Cambrian gneisses and quartzites are given.

Of 25 analyses of the Stockbridge limestones given by President Hitchcock,[1] 12 show it to be pure calcium carbonate. The remaining samples are strongly magnesian but quite free from silicious impurity, while in 5 analyses of pre-Cambrian carbonates the rocks are nearly pure dolomites with an average of 11 per cent of silicious impurities.

GEOLOGY OF FERNCLIFF RIDGE IN LEE.

CAMBRIAN QUARTZITE.

The geology of the prominent ridges which rise within and just east of the village of Lee (see map, Pl. VII) is complicated by the unexpected appearance of an outlier of the Cambrian tourmaline-bearing quartzite in the midst of the normal Silurian series.

This quartzite forms a peculiar ridge, which starts with Ferncliff, in the middle of Lee, and is a picturesque steep-sided mass of native rock, in whose eastern side an interesting cave has been formed by the falling of the jointed quartzite from the vertical face of the cliff.

[1] E. Hitchcock: Geol. Report of Mass., 1841, passim.

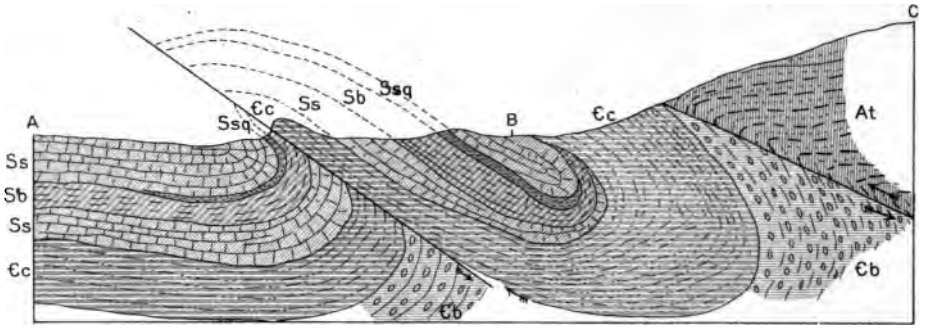
The ridge has been cut through by the river, but rises immediately on the north side and runs a mile farther northwest, presenting vertical cliffs to the east and lower bluffs to the west, where its shape is masked by a thick coating of drift. It ends abruptly at the south end of Laurel Lake, its northern and western faces showing 100 feet or more of vertical or overhanging cliff.

Lithology.—In Ferncliff the Cambrian series is represented by a thin-bedded micaceous quartzite, quite gneissoid in its granular texture and its irregularly disseminated biotite scales, and although it is slightly feldspathic it is not sufficiently so to be called a gneiss. It is uniformly fine sandy granular, and abounds in minute well-formed brown tourmalines in six-sided prisms. It is full of small lenses and pockets of quartz, and the tourmaline, in irregular aggregates, is much concentrated in and around these small veins and in their prolongations, being here much larger, some prisms reaching fully an inch in length.

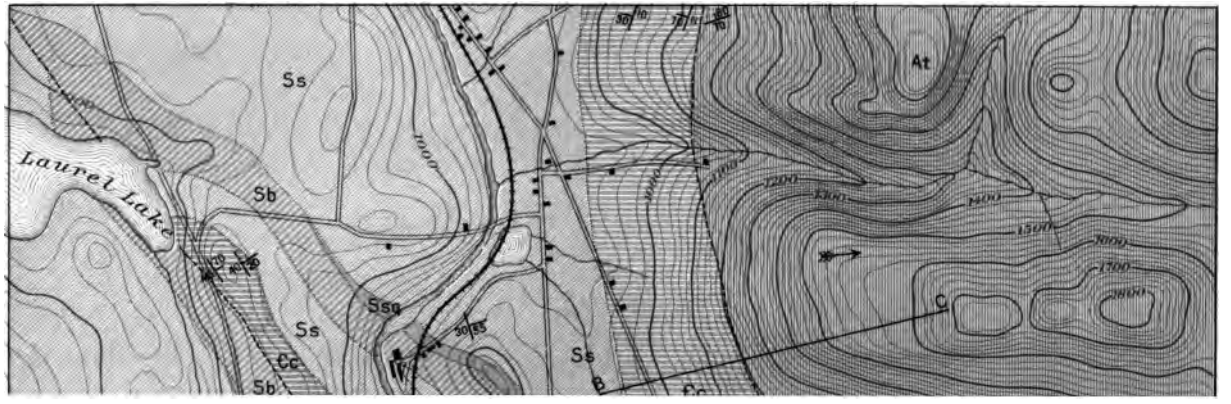
This bed, 40 or 50 feet thick, makes the crest of the ridge, and beneath it is a more micaceous quartzite or arenaceous mica-schist, always having a sandy quartz base, but often dark gray in color, owing to the abundance of biotite mixed with the muscovite. This also regularly contains tourmaline, in shapeless groups of needles, clear down to the edge of the river at the north foot of the hill. The same conditions exist in the ridge to the northwest. The rock is tourmaline-bearing from top to bottom, except in the middle of the east face of the steep hill which forms its north end, where there is, in considerable force, a pure white quartzite containing only a few minute pyrite cubes. It is, however, more granular than the Silurian quartzite to the east and more regularly banded, and layers immediately above and continuous with it contain much mica and tourmaline.

Structure.—In Ferncliff the rock is much contorted in the west face of the ridge; its beds dip east into the hill, with high angle, and emerge in the same direction, with low dip to the east as a whole but with large low undulations of the beds to north and south and with low dips to the west in some places, as at the cave.

On the north face of the Ferncliff hill the beds dip first 20° E., then 30° E., where they are on a level with the Silurian quartzite to the west; 60 feet lower, at the river bank, they are nearly horizontal, with low dip south. At the north end, in the same way, the dip is 70° to 80° E. all the way up the west face, with low easterly dips on the east side. In the high ground of the valley border, several miles to the east, the equivalent of these rocks appears as the Cheshire quartzite, which graduates into the Becket gneiss, and they are here, for a long distance north and south, characterized by an abundance of minute stout tourmaline prisms. They are much more highly metamorphosed than the Silurian rocks with which they are here associated.

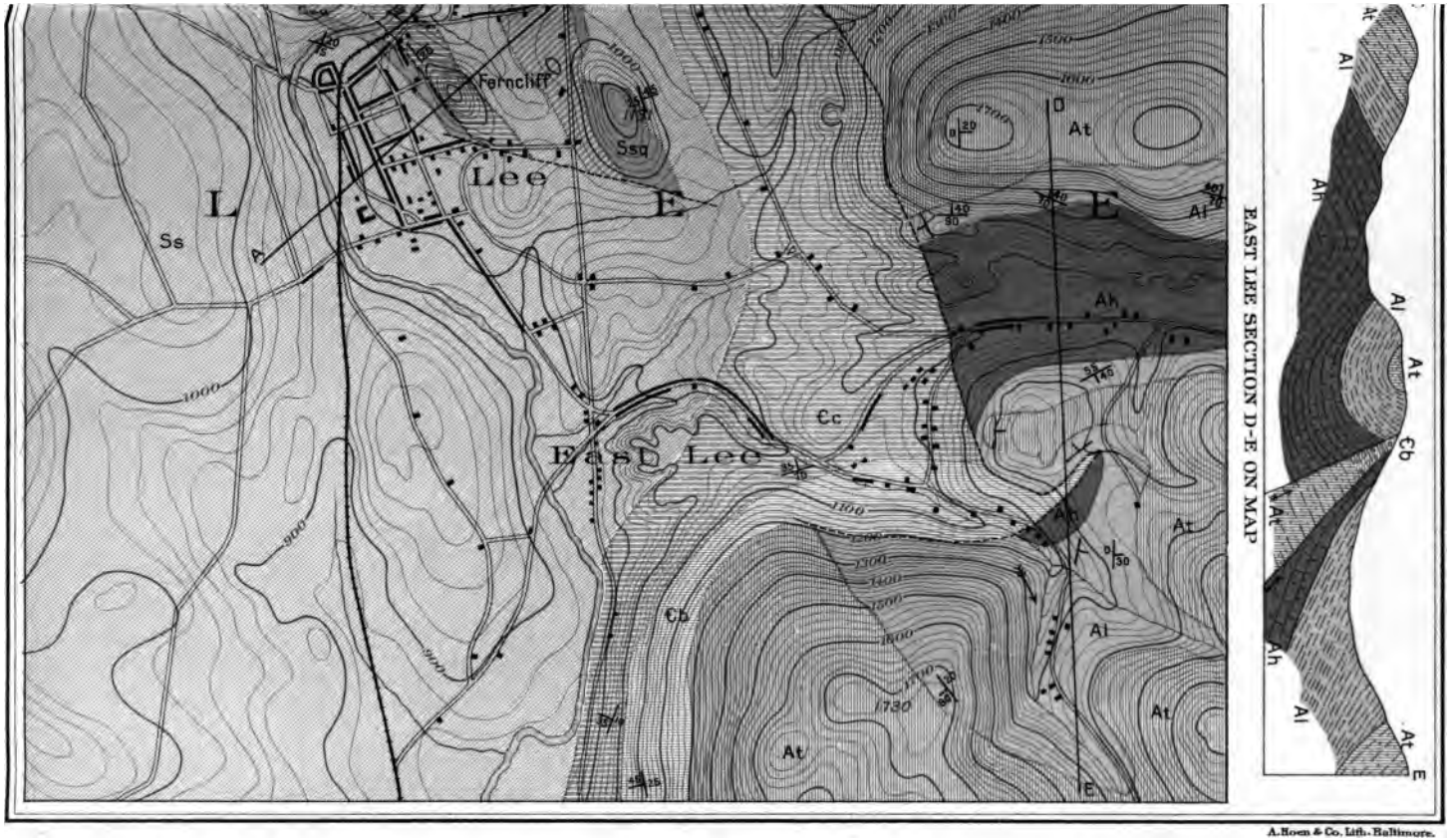


FERNCLIFF SECTION A-B-C ON MAP



LEGEND

- Berkshire Schist
- Quartzite in Sandstone
- Stockbridge Limestone
- Cheshire Quartzite
- Cb — Becket Gneiss
- Tyringham Gneiss
- Lee Gneiss
- Hinsdale Limestone
- Dip
- Pitch



A. Hoen & Co. Lith. Baltimore.

GEOLOGICAL MAP OF FERNCLIFF AND EAST LEE

Scale of miles

½ 0

1898

SILURIAN SERIES.

LOWER LIMESTONE.

The lower band of the Stockbridge limestone which appears in this area is deeply buried in the low valley bottom and rarely exposed at all. At the railroad crossing in the north edge of Lee village, opposite the Columbia mills, where on the map the eastern quartzite band crosses the road and railroad, is a section which shows all the remaining rocks of the area in excellent exposure, all dipping eastward in apparent conformity, and just south, along the railroad, the lower limestone is also well exposed in the cutting. It is full of phlogopite in bands, especially at the top, of altered pyrite in pentagonal dodecahedrons, of granular colorless muscovite, and of quartz grains. Its calcite grains are much twinned.

It folds around a large lens of a very coarsely crystalline and limpid marble, and is as a whole so much more crystalline, translucent, and filled with minerals than the soft, fine, sugary limestone of the upper bed as to strongly suggest that it may belong to the pre-Cambrian limestone, like that of the East Lee Valley. I could not find chondrodite or pyroxene in it, and consider it a Stockbridge limestone rendered more highly crystalline than usual, perhaps by the influence of faulting.

The accompanying analysis of a specimen of this limestone, from the railroad cut in Lee, also goes far to prove that the rock is to be associated with the Stockbridge limestone. The analysis was made by Mr. George Steiger in the laboratory of the United States Geological Survey.

Analysis of limestone from cut west side of railroad, north of Lee village.

	Per cent.
SiO_2	0.95
TiO_2	None.
Al_2O_3	.09
Fe_2O_3	None.
FeO	.10
CaO	54.75
BaO	None.
MgO	.56
K_2O	.15
Na_2O	.02
Sl_2O	None.
Water 100°—	.08
Water 100°+	None.
SO_3	.05
P_2O_5	.03
CO_2	43.38
Total	100.16

I have elsewhere brought together (see p. 69) four analyses of the pre-Cambrian limestones of western Massachusetts. They are all nearly pure dolomites and contain an average of 11 per cent of siliceous impurities.

In a list of 25 analyses of the Stockbridge limestones 12 are nearly pure calcium carbonate, and those which contain magnesia are nearly always free from siliceous impurity.

BERKSHIRE SCHIST.

This mica-schist, which is well exposed just east of the railroad crossing on the foregoing section and in many places to the south as well as along the southwest shore of Laurel Lake, is a felted mass of warped red-brown biotite scales, generally of quite ragged appearance, rusting readily, and without accessories.

SILURIAN QUARTZITE.

The quartzite which appears near the schoolhouse just west of Ferncliff, and which has been recently opened for road material across the river to the northwest, agrees exactly in composition with that of the ridge a mile east of Ferncliff. It is the usual pure, massive, pale-yellow, vitreous quartzite.

It diminishes rapidly in thickness toward the west and north. At the south end of the east band it composes the whole of the massive hill just east of Lee (1,131 feet high), while where it crosses the railroad it is less than 50 feet thick. Farther north the rocks are everywhere covered, but all the indications of topography point to its entire disappearance, as at the north end the mica-schist ridge slopes down gradually into the low limestone plain, whereas a strong ridge would rise to the east if the quartzite were present. The quartzite west of Ferncliff is also only about 50 feet thick, and seems to thin out to the northwest so that it ceases to have influence upon the topography.

UPPER LIMESTONE.

This is the common Stockbridge limestone, white or pale gray, friable, generally pure in this vicinity, except that tremolite is abundant in the quarries to the south of the town.

FAULTS.

The representation of a north-south Ferncliff fault is justified by the close approximation of the Silurian quartzite to the Cambrian quartzite in Ferncliff, followed by the similar approximation of the Silurian mica-schist at the north end. It is drawn parallel and symmetrical with the main Lenox fault, which runs at the foot of the mountain to the east, as an overthrust subordinate to the main one, and most simply explains the structure of the region.

Justification for the hypothesis of an east-west fault is found in the fact that on reaching this line the two strong quartzite ridges suddenly stop and the whole area before them lies at the low level of the limestones, so deep indeed that over a square mile there are no outcrops at all. It *is thus much* more probable that these resistant beds are faulted down

than that they form the surface across to the edge of the mountains, where they appear again in undiminished thickness.

This fault, prolonged easterly, runs up the East Lee Valley, where it or another fault south of and parallel to it, which is given with query on the map, terminates the Lenox fault and is marked by the overthrust of the pre-Cambrian on the Cambrian. It also runs parallel to the great Tyringham Valley fault to the south.

SIGNIFICATION OF THE NORTHWESTERN THINNING OF THE SILURIAN QUARTZITE.

I have elsewhere shown that the Tyringham and East Lee valleys were early blocked out because of the solubility of the Hinsdale limestone, and this thinning out of the coarse sediments, represented by the two quartzite bands (see Ssq, Pl. VII), along lines radiating from the mouth of the East Lee Valley, may mark a time of exceptional elevation of the Berkshire Valley border and of strong drainage through the long East Lee-Otis depression. In other words, the quartzite and associated band of Berkshire schist represent the remains of the delta deposit of a stream flowing west down the East Lee-Otis Valley during Lower Silurian time.

FAULTS.

HINSDALE FAULT.

This fault runs north and south through the village of Hinsdale. Along the whole western border of the Hinsdale anticline north of the Plunkett reservoir the Washington graphitic gneiss is absent and the Lee gneiss comes successively into contact with the Cambrian Becket gneiss, the Washington gneiss of the Dalton anticline, and the Stockbridge limestone.

A mile south of Hinsdale, at the top of the hill just west of the large outcrop of limestone near the bridge over the railroad, and again 90 rods west of the last inhabited house (C. D. Barrett's) on the blind road running north from the cemetery, the Lee gneiss can be seen in immediate proximity to the Becket gneiss. The fine-grained micaceous quartzite (Cambrian) has a strike N. 10° W. and a dip 65° W. The amphibolite and banded gneisses (Lee gneiss) adjacent on the east have a strike N. 50° W. and a dip 80° W.

Farther north, at J. Hanrahan's, south of the road running east from Dalton, the Lee gneiss carrying allanite is for a long distance in immediate proximity to the great outcrops of Stockbridge limestone, showing that the fault is one of great importance and concealing the whole Cambrian and Upper pre-Cambrian beds.

DALTON FAULT.

From the high iron bridge near the Dalton railway station the crumbling white Stockbridge limestone can be seen to form the north bank of the Housatonic for a long way west, while the fluted surface of the massive Cheshire quartzite forms the steep south bank.

At the ruined pier of a proposed bridge this fluted surface dips 80°

N. in the upper portion of the bluff, 50° and 40° in the lower part, and represents the fault surface, being horizontally ground and slickensided by the horizontal thrust of the fault. The limestone appears in the northern bank of the narrow stream to the next iron bridge, where it includes quartzite beds and forms the bed of the stream, with a constant strike N. 20° E. and a low westerly dip of 20°, as at the Carson and Brown paper mill, just west. Here the adjoining rock on the south of the fault is a dark, corrugated mica-schist, abundant in the hills to the south, and in boring an artesian well at this mill and 2 or 3 rods north of the stream the auger went through the limestone for 135 feet and then dropped 3 feet onto the surface of the mica-schist, which was bored 9 feet. I found chips from this boring identical with the schist in the hill to the south. This gives the fault here a hade to the north about the same as the quartzite plane mentioned above. The well record is interesting and is given below.

The faults on the north and south of the Dalton anticline were formed by the crushing together and the uplifting of this anticline, and an inspection of the map will suggest that the two areas of mica-schist north and south of the fault may once have been continuous, and the part to the north have been pushed eastward by the throw of the fault.

It may have been a muddy band sent out over the bottom of water where for the most part limestone was forming, and have been continuous eastwardly with the remnant in Windsor and the Hoosac schists farther east.

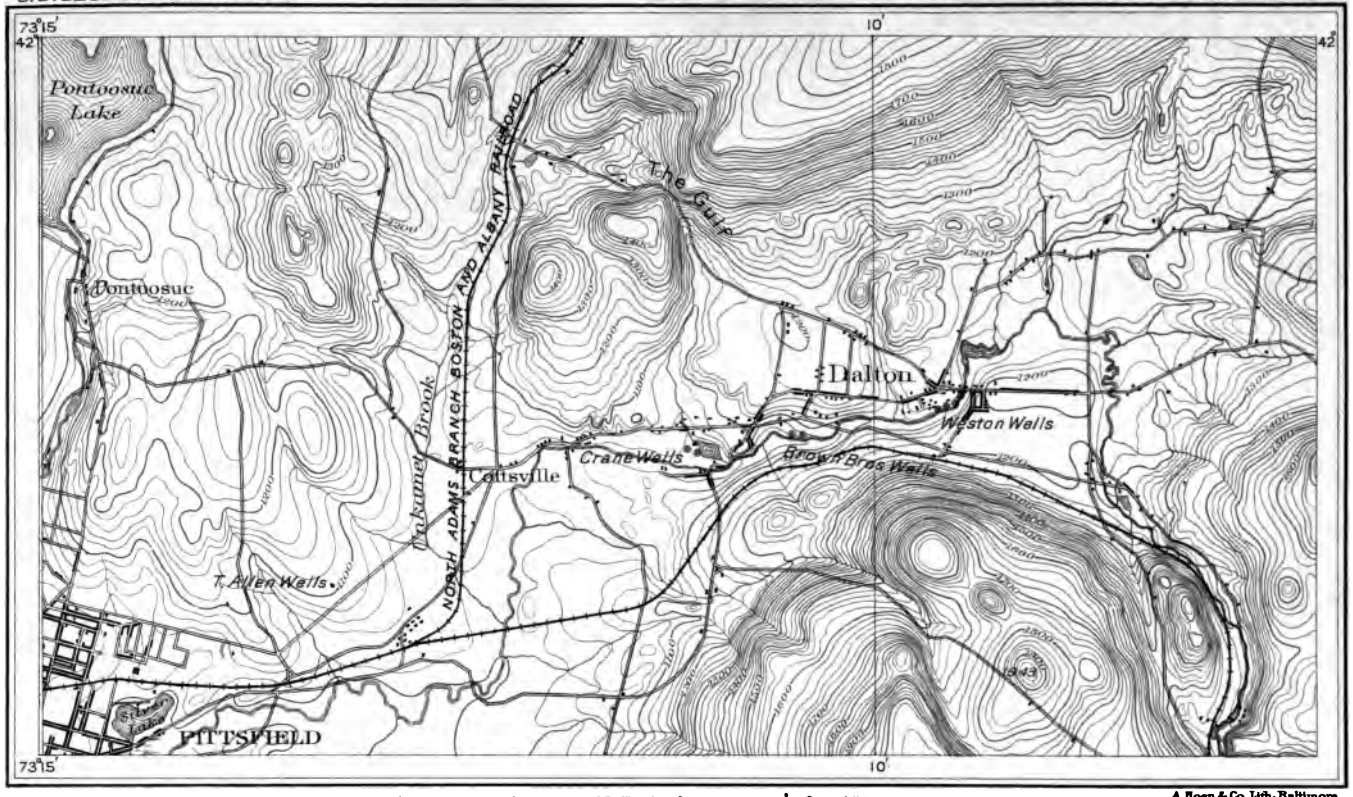
ARTESIAN WELLS UPON THE DALTON FAULT.

The great paper-making mills at Dalton owe much of their high reputation to the abundant artesian water, of excellent quality, obtained from very shallow wells bored upon the Dalton fault. (See Pl. VIII.)

At the Carson and Brown mill, beside the Housatonic River, in the west part of Dalton village, two interesting artesian wells have been bored. One was commenced March 7, 1884, by D. Dull, of New York. The following record was given me by Mr. Brown:

Record of well borings at the Carson and Brown mill in Dalton in 1884.

	Feet.
Soft rock	25
Hard rock	84
All way hard rock	98
Little water ran over	99
Soft rock	101
Soft rock	102
Very soft rock	104
Very soft rock	109
Very soft rock	114½
Very soft rock	117
Very soft rock; first water run	122
Very soft rock; increased water run	126
Very hard rock	131½
Broke through to soft rock and gravel 3 feet deep; water doubled.	135
Solid rock again	138
Continued 9 feet in the same solid rock	147



ARTESIAN WELLS ON DALTON FAULT

A. Roen & Co. Lith. Baltimore.

Scale

1 0 1 2 MILES

The well supplied 740 gallons a minute *of the purest water. The* upper rock was limestone. The drill fell in a cavity formed by solution of the base of the limestone by water circulating along the plane of the fault. The lower rock was the corrugated mica-schist, as shown by samples preserved.

In 1855 a well was bored on the west side of the mill near the river by S. S. Gilman, of Springfield. The following record was preserved:

Record of well boring at the Carson and Brown mill in Dalton in 1855.

	Feet.
Rock blue lime	24
Rock blue lime	24–37
Gray band; first water	37–40
Gray lime	40–67
White belt; large water vein, flowing well	67–71
Increase of water	71–100

"The rock is soft lime mixed with soapstone." The soapstone was probably the decomposed micaceous portion of the limestone.

An analysis of the water gave the following results:

Analysis of water from artesian well in Dalton.

[Parts in 1,000,000=140.3 solid.]

	Parts.
SiO_2	8.80
Al_2O_3	12.80
CaO	33.15
MgO	23.06
K_2O+Na_2O	22.54
FeO	Trace.
Cl	3.55
CO_2	36.40
$CaCO_3$	59.15
$MgCO_3$	35.06
NaCl	5.85
SiO_2	8.80
Al_2O_3	12.80
K_2O	18.64

The wells in the village of Dalton to the north and east lost their water when the first well was opened. Other wells have been bored along the same fault, at Mr. Byron Weston's mills farther east, but the wells bored at the Crane mills to the west were unsuccessful and were plainly not along the line of the fault. The following report on the wells at the Weston mills, 250 rods east along the same fault, has been prepared for me by Mr. W. L. Tower, civil engineer in Dalton:

Number of wells, 5, of which 4 are in use:

No. 1, the Bonanza, is 239 feet deep and was bored in winter of 1883–84. First flow of water tested January 24, 1884, showed 366 gallons per minute. After further boring more water was obtained, and the flow has perceptibly increased since the well was completed. The latest test shows a flow of 550 gallons per minute with a

pump lifting the water 18 feet out of well. The boring drills and part of the apparatus were lost in this well, and it is thought that this fact diminishes the flow of water.[1] The rock is reported to have been principally very soft limestone. Operations in boring this well were very much delayed and hindered by caving. It was bored by Daniel Dull, of New York City, who saved samples of the rock passed through in boring the Bonanza and Deep wells.

No. 2, Deep well; 511 feet deep; bored in fall of 1883. Flow, 260 gallons per minute. Bored by Daniel Dull. Rock passed through medium to hard limestone and a vein of very flinty rock at a depth of about 300 feet.

No. 3, Chamberlin well; 150 feet deep; bored 1856–57. Flow, 120 gallons per minute. Bored by Mr. Gilman.

No. 4, Defiance well; 76 feet deep. Flow, 28 gallons per minute. This well is about 400 feet northeast of the Bonanza well. Surface rock in the immediate vicinity, as uncovered in summer of 1895, soft seamy limestone. Bored by Jesse Button, Springfield, Massachusetts. An analysis, made at Yale College, of the water of the Bonanza, Deep, and Chamberlin wells, determined that it is very hard, contains carbonates, is unfit for use in boilers or laundry.

There is a fifth well at Weston's mills, near the Deep well bored by Jesse Button, but it is now abandoned. The well has a temperature of 48° for summer and winter.

SOUTH DALTON OR WARNER MOUNTAIN FAULT.

The west end of this fault can be well studied a hundred rods north of where the road from Pittsfield to Washington Station first crosses Sackett Brook, in a narrow gorge running east and west and forming the gathering ground of a small brook, shown on the map, that runs west, crosses the north and south road, and joins Sackett Brook.

The north wall of this narrow valley is composed of the dark Becket gneiss, the south wall of the pure Cheshire quartzite, and they both strike north and south and dip west.

Going west to the next point where Sackett Brook crosses the road, one may take a wood road north from the western house (J. Sweeney's) of the small settlement 100 rods up the mountain side and 100 feet above the main road to a group of logging huts near a bridge.

Five rods up the brook, above this bridge, one finds the white quartzite on the south abutting against the dark Becket tourmaline-bearing gneiss in a well-marked vertical east-west fault, which can be traced in the bluff a long way east to a point where, north of the eastern house of the village (W. Kirschner's), the quartzite begins to come in contact with the older gneiss, and where the junction of the two gneisses is also well exposed a long distance in a steep bluff.

The fault limits the Dalton normal anticline on the south. South of the fault the quartzite extends a mile farther east than on its northern side. All along the roadside, south of the great southward-facing scarp caused by this fault, are numerous great bowlders of a coarse quartzite breccia cemented by much limonite—a friction breccia derived from this great fault. (See p. 80.)

At a point a half mile north of the top of Warner Mountain the

[1] This was probably because the fault plane was struck at this point and the tools fell into the cavity, as in the case of the Brown Brothers' well, before mentioned.

corner of the pre-Cambrian area can be clearly mapped in the bare hilltop. From this point east the country is covered, but the formations that come up to it on the north and on the south are so diverse that the prolongation of the fault is certain, and its exact position can not be anywhere far from the line given on the map. It is, however, not certain that it cuts off the pre-Cambrian limestone at the overhead bridge south of Hinsdale village, although this is by far the most probable representation of this badly covered area.

LENOX FAULT.

A half mile south from New Lenox Roaring Brook comes down from the mountain. Following it up 100 rods from the road over the distinctly bedded quartzite, which strikes 45° E. and dips 50° W., increasing near the contact to 60° W., the contact above can be seen in the side of the wood road which follows the brook on the north side, and below in the bank at a fine waterfall. The quartzite is here thick bedded and much contorted, especially a little farther south, and its posture is constant. It is vertically jointed for several feet west from the contact and a few scales of muscovite appear on the foliation faces.

The gneiss rises in a great bluff above the quartzite, and this bluff extends a hundred rods north and several miles south to the East Lee Valley. The gneiss is highly stretched, with strong pitch south. It is much crushed and agrees in type with the Tyringham rock. Many bowlders of the coarse Washington blue-quartz gneiss, blotched with great masses of biotite, have fallen down, and the contact of the two formations is in the bluff above.

A still more interesting exposure of the same contact is found a mile east of Lenox Furnace (fig. 8, p. 44). A wood road runs east from a sharp bend in the main road, and the section shown in the figure begins where this road crosses a brook and continues along its side.

The contorted quartzite at the brook crossing seems to have a rather low dip west, but the finer, flaggy quartzites higher up dip steeply to the west, which seems to be the posture in the beds; flattened pebbles are found higher up. These beds and the thick, granitoid quartzite which follows (and which, as in the Dalton clubhouse section, is characterized by a pale-green muscovite) are full of small tourmalines and connect with the Cambrian.

At the contact, which occurs in a great white ledge south of the brook just before reaching the thick woods, only a rod of a true Becket gneiss intervenes between the micaceous quartzite and the black-and-white pre-Cambrian gneiss. There is a conformity of foliation at the junction, but while the quartzites strike north the older gneisses strike nearly east, and the extent and character of the fault can not be determined. It depends upon the thickness of the gneissoid lower member of the Cambrian, and this is variable; at times the Cambrian seems to be a quartzite to its base.

Five rods east of the contact of the section shown in fig. 9 on page 45, at the point where the road from Lenox Furnace if prolonged east would cut the 1,400 contour line, is the contact of the white-and-black banded Lee gneiss and a stretched gray Tyringham gneiss. The wood road runs over bare rock at this point, and there is, resting unconformably upon the vertical edges of the Lee gneiss, a thin veneering of a dark jointed Cambrian slate containing small pebbles.

The complex series of faults near East Lee can be only partially deciphered, and their connection with the Lee faults is not clear. The matter is discussed under the sections describing the East Lee limestone (p. 50) and the Ferncliff faults (p. 88).

TYRINGHAM FAULT.

The Tyringham fault has had much to do with the formation of the deep Tyringham Valley. How much it has been assisted by the solution of the pre-Cambrian limestones can not be determined.

It brings the pre-Cambrian up against the Cambrian in the mouth of the valley, probably hades north, and is upthrown on the north side. Lower down the valley it has brought Cambrian and pre-Cambrian together, and in its continuation has formed the upper valley of Clam River, as the Otis fault has fixed the upper course of the Farmington River.

INTRUSIVE ROCKS.

Intrusive rocks, both basic and acid, are almost absent from the Becket and Sandisfield quadrangles, except so far as the pre-Cambrian rocks are altered eruptives. West of the great granite stocks which look down on the Connecticut Valley and their broad fringe of dikes, the isolated dike of porphyritic granitite in Middlefield is almost the only acid intrusive which approaches this territory. The greatly altered black massive hornblendic rocks of Becket and of Ball Mountain and vicinity, associated with the Cambrian gneisses in the extreme southwest corner of the area, are the only exception among the basic rocks. The same is true of the extension of this area to the north across the State. Two small, much-altered dikes of basic rock are indicated by Professor Wolff in the Hoosac Mountain map as northeast and southeast of the village of Berkshire, and a third pre-Cambrian dike is described from Oak Hill, on the north border of the area. The same seems also true of Greylock Mountain and of the Taconic Range for a considerable distance to the west. The basic rocks of the Cambrian are described on page 69, in order to compare them with the amphibolites formed from sedimentary beds.

Pegmatite.—A well-characterized graphic granite is represented in Mr. D. Clark's collection, which was obtained from the roadside in West Otis village. The granite 50 rods below Windsor Falls, in Dalton, south of the brook, contains good crystals of orthoclase and a little actinolite in biotite, and is soaked full of a lemon-yellow iron salt due to

change of biotite and actinolite. In the southwest part of the Sandisfield quadrangle small pegmatite veins and impregnations are quite frequent, but not extensive enough for mapping. They present no peculiar characteristics except at the occurrence north of Town Hill, in Sandisfield, where the crushing has sheared the large tourmalines in a remarkable way into a series of echeloned plates. The small pegmatite dikes bordering the amphibolite at the Becket quarry are described on page 75, and those at the West Norfolk cut on page 77.

GLACIAL DEPOSITS.

The whole upland country is covered by drift, often very heavily, especially in the south of Becket and the north of Otis, but presents little of special interest.

POST-GLACIAL DEPOSITS.

The Hoosac limestone valley is continued south over a low pass in Lanesboro into the broader Housatonic Valley at Pittsfield by way of Unkamet Brook. The Hoosac Mountain Range from the north line of the State to the north of Dalton presents so steep and uniform a slope to the west that it forms an unbroken line of division between the Champlain deposits on both sides of the range. When, however, the limestone expands eastward in the center of Dalton a partial union occurs.

This Dalton bay is deep, being underlain by the Stockbridge marble, which is easily removed by erosion. It is, moreover, continued southeast across Hinsdale and Washington by a curious transverse depression in the Berkshire Hills, which, although at a much higher level than the Pittsfield Plain, is yet much below the crest of the ridge. It begins narrow, at its southeast corner, and extends as a broad depression across Hinsdale, where it drains west as the Housatonic, and is continued beyond the Washington station, where it expands into a deep amphitheater and suddenly narrows into a canyon, which continues into Becket and contains the head waters of the Westfield River—a tributary of the Connecticut.

When the boundaries of the complex overthrown Hinsdale anticline were made out, the lowest easily decomposing beds of the pre-Cambrian nucleus of this anticline were seen to have conditioned this depression, which is divided at the Washington station by a dam of the decomposing gneisses about 1,550 feet above the sea. These furnished the barrier which fixed the level of the Hinsdale lake in Glacial time, and which forms the watershed of the present topography.

WASHINGTON BASIN.

As the ice melted up the Westfield River Valley it at last set free the canyon already mentioned, between Becket and Washington stations, and the deep amphitheater into which the canyon expands

just before reaching the latter station. As the waters escaped from the ice and passed through the gorge, they left a great body of sand in the basin, and this at a time which slightly antedated the formation of the Hinsdale lake described below.

For nearly a square mile north of Washington Station the broad, flat-topped sands stand 80 feet above the bottom of the Hinsdale lake. Recent extensive excavations by the railroad along this plain showed that for long distances it is composed of broad, undulating sheets of nearly horizontal sands and gravels, bending down on the south, with delta front structure. They were probably laid down when the ice still occupied most of the Hinsdale Basin to the north and had just begun to send its waters down the newly opened gorge to the south.

HINSDALE LAKE.

A description of the heavy gravel and fine sand deposits which fill the basin back (north) of the Washington sand plain across Hinsdale and which end abruptly in a terrace scarp on the east edge of Dalton, high above the level of the sands in the Pittsfield-Dalton Valley, will be best appreciated if given in the terms of the theory which seems to explain them.

The sands seem to have been deposited while the ice, having just abandoned the Hoosac Range to the east, still filled the limestone valley to a point south of Pittsfield and projected into the Dalton bay, completing the boundary of the lake near the present western boundary of Hinsdale Township, and about a mile north of Hinsdale village.

The Washington gneiss barrier determined the height of the waters, and heavy floods from the north and northwest swept across the ice and into the lake, carrying great masses of sand and gravel which, exactly as in the filling of a mill pond, were deposited in the upper part of this lake, filling the narrow northern portion from the point where the ice stood, across the area where is now the Catholic cemetery, extending southward, and expanding with the widening of the basin to a broadly curved line just south of Hinsdale village.

The great plains to the north and east of the village (the level of Maple street), about 1,520 feet above the sea, are a remnant of this extensive deposit, and the magnificent terrace scarp which starts from the road running southeast from the town library and about 50 rods from that building and runs a half mile east to the next road, is the terrace front of the great delta that was advancing into the lake when a period was put to the lake itself.

On the recession of the ice northward into the Dalton bay, the lake drained, forming the present Housatonic River and cutting away much of the old delta. The sand which had rested against the ice caved to a terrace scarp sloping north toward the Dalton bay, traces of which scarp can be seen just north of the Catholic cemetery.

In Hinsdale one must mentally restore the level of Maple street, the

broad plain east of the village, and carry it across to the hillside on the west of the village, in order to understand the great sand deposit, for brooks and temporary washouts have carried forward the destruction begun by the breaking away of the lake.

From the foot of the great delta front below the library a broad, flat plain of fine sand extends south, the whole width of the basin, to the foot of the transverse sand plain in the Washington Basin which bounds the lake on the south.

The plain descends slightly to the south and the river meanders slowly across its flat surface. The fine sands were being spread over the bottom while the great gravel delta was advancing into the basin and gradually covering them. The high delta flats at Hinsdale and at Washington Station and the lake bottom bed between them can be clearly made out from the contours on the inch-scale map.

DALTON KAMES.

A great kame starts high up on the Wakonah Falls Brook in southwest Windsor. The broad, open valley is in its northern part and for a long way south bottomed by till, and is then suddenly covered by gravels which gain great thickness southwardly before they reach the reservoir 3 miles northeast of Dalton. Southeast of the latter place, in the northwest of Hinsdale, similar sands expand in a broad basin. These join the Windsor sands and extend west down the Wakonah Brook Valley into Dalton as a well-sorted gravel kame of large dimensions (a long sand plain abounding in deep pits) which winds strangely across Dalton and is finally submerged beneath the broad sand stretches which expand westward from the Pittsfield plains.

It is clear that these gravels began to be deposited when the ice still filled the Dalton depression, and that the waters that brought them had then an outlet south across Ashmere reservoir into the Hinsdale lake; that, as the ice lowered, the drainage of West Windsor and North Hinsdale ran southwest across the ice, by Wakonah Brook, into the Housatonic Valley. Later the horizontally stratified gravels were let down by the ice remnants on which they partly rested and sank to such a level that they were in places wholly, and in places only partially, submerged by the sands which were afterwards swept south through the Hoosac Valley and spread on the Pittsfield-Dalton Plain.

HIGH TERRACES IN BECKET.

A high mountain ridge extends northwest from Becket Mountain, and for several miles is flanked by two great terraces, at 2,080 and 2,000 feet, which seem to be the remnants of a glacial lake whose waters finally drained into Basin Pond Brook. These terraces can be reached by the blind road west of the reservoir. They have not been made the subject of special study.

HIGH SANDS AT ENTRANCE TO EAST LEE VALLEY.

Standing on the hill south of Lee and looking across to the entrance of the East Lee Valley one sees that the whole broad mouth of the valley is clogged by exceptionally high, flat-topped sands, which project into the valley in great lobes. They have been notched by the cutting for a railroad that was never finished, and, as usual, have a cemetery on their flat surface. They represent the filling of a temporary lake, held up by the Berkshire Valley ice and drained southeast down the East Lee Valley.

DEFLECTED GLACIAL DRAINAGE DOWN THE HINSDALE, EAST LEE, AND TYRINGHAM VALLEYS.

Each of these long valleys has been greatly affected by the movement of the ice out of the Berkshire Valley, and by the deflection of the flood waters during the meeting of the ice.

From Hinsdale down the Westfield River, from East Lee down the Farmington River, and from Tyringham down the Clam River, this influence is felt the whole length of the valleys and out across the Connecticut Valley in Massachusetts and Connecticut. Bowlders of blue-quartz gneiss are not rare here, while the "hardheads" of the Cambrian quartzite from the Housatonic Valley are everywhere very common.

MINERAL RESOURCES.

LIMESTONES.

Pre-Cambrian.—The time has long past when the Hinsdale limestone was burned for quicklime. Most of it is too impure for architectural purposes. The limestone at the mouth of Coles Brook, in which the chondrodite grains have changed to pale yellow-green serpentine, is adapted to ornamental purposes, and the heavy bed, crossed by the Housatonic branch, southwest of Hinsdale is very pure and of even grain, firm and of good luster, and ought to be considered as a source of marble.

Silurian.—The Stockbridge limestone or dolomite is quarried extensively for local uses in the deep bays which penetrate the Hoosac Range in Dalton and Tyringham, and the important quarries south of Lee village have furnished large quantities of high-grade marble, from which the Washington Monument, the Capitol extension, Girard College, the new city hall in Philadelphia, and St. Patrick's Cathedral in New York City were built. It is a white, durable, but rather coarse marble, and cubes 20 feet on a side can be furnished from the quarries. It sustains the highest tests for crushing strength.

Analysis of white dolomite from Lee, Massachusetts.

[G. P. Merrill: Cat. Nat. Mus., 1889, p. 505.]

	Per cent.
Carbonate of lime	54.621
Carbonate of magnesia	43.932
Oxides, iron and aluminum	.365
Loss	.610

Tests of strength of dolomite (marble) from Lee, Massachusetts, at Watertown Arsenal.

[G. P. Merrill: Cat. Nat. Mus., 1889, p. 497.]

Size of cube.	Position.	Strength per square inch.	Remarks.
5.91+ 5.92+ 5.92	End	22.860	Sustained maximum load of testing machine without apparent injury.
5.91+ 5.91+ 5.90	Bed	22.900	Flaked off along one edge.
5.89+ 6.00+ 5.90	Bed	21.700	Crushed suddenly with report.
5.9+ 5.91+ 5.90½	End	20.504	Burst into fragments suddenly.
5.93+ 5.93+ 5.93	Bed	22.370	Effect of loading, slight flaking of one face of block; did not break.
5.92+ 5.92+ 5.91	End	22.820	Sustained maximum load of testing machine without perceptible injury.

GRANITE.

Pre-Cambrian.—The coarse gneisses of the pre-Cambrian series have been quarried for common work, like bridge building and underpinning, but have been used only locally. They rust badly, and may crumble.

Cambrian.—The conglomerate-gneisses are often so strongly metamorphosed that they become complete granites. This seems often to depend on their proximity to sharp upfolding of the pre-Cambrian rocks. The best quarry is that of the Chester Granite Company, in the southeast corner of the Becket quadrangle. This granite is fine-grained and clear gray, a little too dark for polished work but taking a fine surface and furnishing large blocks of even grain and color, suitable for the best monumental work. A similar stone has been much worked in the Clark quarry, beside the railroad west of Coles Brook. Here the passage of the massive quarry stone into the common flaggy gneiss can be clearly seen. A promising quarry has been opened on N. Alderman's land, in the center of Becket, and in Otis the quantity of good granite is inexhaustible. In the south part of the area in New Marlboro and Norfolk a rock of the same age and character has been much quarried, especially on the east slope of Ball Mountain.

FLAGSTONES.

The Cheshire quartzite is mentioned by Hitchcock as furnishing the most perfect flagstones in the State. The best quarries were in the west part of Washington, 5 miles southeast of Pittsfield. Other quarries occur in Tyringham and Lee. Little work, however, seems to be done on these beds now.

BUHRSTONES.

In the same hill in Washington in which the flagstones occur buhrstones were formerly quarried which sold for $70 to $80 each. This industry also has passed away.

GLASS SAND.

Where the Cheshire quartzite extends far up into the mountains in Washington much glass sand is dug and carted down to the railroad. In the western part of Washington also and in the Gulf at Dalton much of the quartzite is pure enough for use in glass making.

ROAD MATERIAL.

In Hitchcock's Final Report on the Geology of Massachusetts (p. 211) is perhaps the first suggestion of a rock for road building in the State. The harder varieties of the Cheshire quartzite are thought to be well fitted for this purpose. It will certainly be the best local rock for this use, but the pure quartzite found in the Stockbridge limestone will be nearly as good. The Gulf in Dalton, the country in Washington south of Sackett Brook and east of New Lenox, the western ridge at Fernside in Lee, and the quarry just north of the river, together with the great hill nearly a mile east of Lee, will furnish material in abundance.

SOAPSTONE.

A large amount of soapstone has been taken out at the quarry beside the brook above Wakonah Falls in the south of Windsor, and recently the bed has been opened west of the old quarry and good, soft, slaty soapstone obtained. Along the same bed, a mile southwest, some work has been done on the hard, green, massive chlorite associated with serpentine. A pale-green, fine-grained steatite occurs in large amount as a selvage on the east of the great limestone bed cut by the east branch of the Housatonic in the southeast of Hinsdale. This would form a beautiful rock for inside work.

IRON ORES.

The pre-Cambrian rocks are very rusty, especially in their upper strata, and have everywhere tempted mining. As this rustiness depends largely upon the decomposition of pyrite it is not a good indication of valuable ore. Considerable digging has been done just east of Hinsdale Center, at N. Alderman's in Becket, and at the Hotchkiss *and Cleveland* mines at New Marlboro. The principal ore is pyrrho-

tite. Nothing has been found to justify expenditure. The Cleveland mine was first opened as a gold mine but latterly has been worked as a nickel mine.

GRAPHITE.

Considerable excavation has been made at the "lead mine" east of Washington Station, on the Lyman place, and openings have been made along the same band at several places to the north and at the creamery near Hinsdale. Graphite occurs in considerable amount on Sky Hill in Tyringham and across New Marlboro, but nowhere in sufficient quantity for mining.

GOLD AND COAL.

The Cleveland mine in New Marlboro was first opened as a gold mine. Buttons of gold and silver *received from the assayers* are shown by the owners. There is no probability that gold in paying quantity will be found within the limits of the area covered by the map. In my notebook are the printed-out answers to the questions of a deaf old man living in the south part of Windsor, the sides of whose house were heaped with great blocks of rock full of rotted yellow mica, which he fondly believed to be gold. The rock had been quarried and brought down by him from the mountain to the east. I tried in vain to persuade him to waste no more labor on the search.

The following items appeared in the Springfield Republican:

1895. Yellow Metal at Hinsdale.—Work of mining gold at the Primrose farm at Hinsdale will begin in the spring. Assays have varied considerably, but all find gold in paying quantities. Ricket and Banks, of New York, have made three fire assays; Professor Suthphen, of Gloversville, New York, has made numerous assays, the last being of sand that yielded $56.33 per ton. A large syndicate in New York City is trying to buy a part of the Primrose farm. The interested capitalists live in Pittsfield. The Fleming farm, owned by George Duncan, of Middlefield, will soon pass into the hands of a syndicate of Springfield men if proper terms can be made.

August 15, 1896.—George M. French has a number of men excavating on his "gold find" preparatory to the final examination by Professor Suthphen, of Albany. Despite the contradictory statements made by different assayers Mr. French still has some hopes and flattering offers as well. The numerous assays made by reliable authorities do not agree. While some find gold in large quantities, others find little or no trace.

I have not visited the farm since the new mine was opened. My earlier study of all the ledges of the region had not led me to expect important gold deposits there. The following similar account is quoted for the interesting legend and note concerning the custom of selling mineral rights in the hill towns.

Long ago there was mining for gold done in that wild region known as "the Gulf," in Dalton, in a very desultory way, however, without capital and with no thoroughness, and by those not expert in prospecting.

The discoveries at Primrose farm have stimulated explorations and inquiry, with results that are surprising and may be important and profitable. We announced exclusively last week Mr. Duncan's purchase of the Fleming farm, which, it is

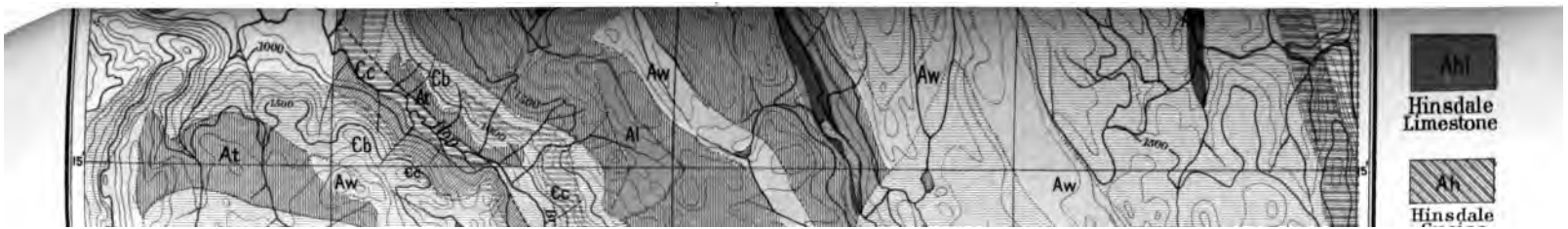
believed, contains a continuation of the Primrose "fissure," and the fact that foreign capital was ready to invest upon assay proof of a good outlook. Mr. Corey, in the town of Washington, but near the Primrose, has had assays made from superficial rock contaminated or impregnated from the Primrose, and finds a yield of $11 to the ton. The William Pease farm, also in Washington, has shown such promise that it has been leased for prospecting and mining purposes by a syndicate from Lee—W. H. Gross, E. Ely, and Mr. Davis, the latter said to be an experienced mine hunter.

That mineral wealth was suspected or believed to exist in these Washington farms is evident from the fact that thirty years ago farms were sold subject to the sellers' reserved right to prospect for and dig minerals. An instance of this is the L. A. Huban farm, owned by father and son, and comprising about 300 acres. This farm adjoins the Pease farm, we believe, leased, as stated, to Gross, Ely, and Davis, and overtures for its purchase by the individual or syndicate for whom Mr. Post is acting were made a good while since. It is only recently, comparatively, that the reservation as to minerals and mining was "bought off" by young Mr. Huban.

There is a legend lingering in the memories of men of Lenox and vicinity that, in the days of legend, an Indian, remnant of a tribe or a descendant of some family of these wandering original Americans, used to tell the white people about a coal deposit he knew of in the woods of Washington. This was before the days of railroads and coal sheds, and when wood was the only and abundant fuel. It is even related that a bottle of "fire water" was offered as a test to prove the assertions, the Indian to have the drink if he brought a pail of coal to Lenox Dale, as he said he could. He was watched, the white man then as now intending to get the best of the Indian, by discovering his secret, but he was too smart for the watchers. He slipped off in the night and returned in the night, bringing the pail of coal. Mr. Huban believes this coal mine is on his farm.

While he was plowing in one of his fields last May he turned up several lumps of coal; a piece of it is now on the Sun's desk. Mr. Huban has owned the place about thirty years, and there has been no such use of coal about the farm as should make its presence probable or even possible. He has done no prospecting, made no examinations to speak of, but is satisfied in his own mind that there is a coal deposit where the outcroppings were struck with the plow.

Of course there is not the slightest possibility of finding coal in Washington, and the prospect of discovering gold in paying quantities is scarcely better. More than fifty years ago President Hitchcock published in his final report a long list of similar legends and foolish searches for gold, in the hope that the tendency to waste money in that direction might be checked with increase of knowledge. I do not, however, find any apparent decrease in the number of "gold mines" in the region.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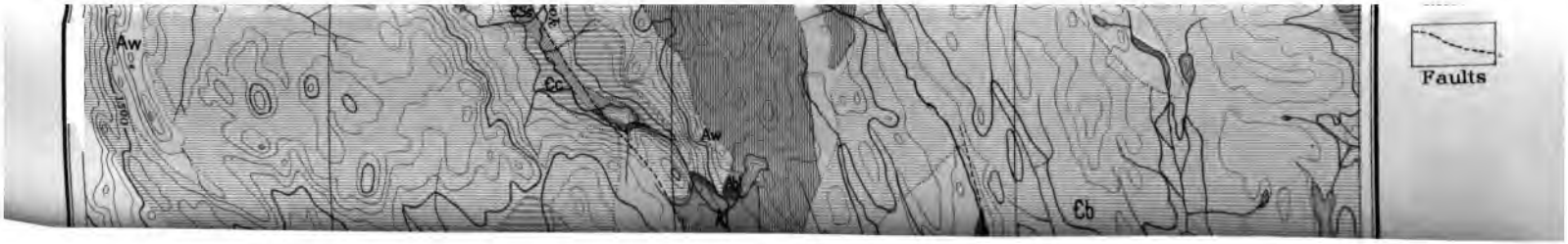
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A MINERAL LEXICON OF EASTERN BERKSHIRE COUNTY, MASSACHUSETTS.

The region covered by this lexicon embraces the towns of Windsor, Dalton, Hinsdale, Becket, Lee, Tyringham, Otis, Sandisfield, and New Marlboro.

An attempt has been made to give a full chronological history of each mineral, its geological age and distribution, and its mineralogical varieties and crystalline form. All sections which are not followed by citations are by the author. The greater portion of the material studied is contained in the collection of Mr. Daniel Clark, of Tyringham, and where it is not otherwise stated it may be assumed that the best illustration of every mineral in the county is to be found there.

ALBITE.

1891. **Albite.** New Marlboro.

A beautiful albite in good crystals a half inch long, showing a fine moonstone effect in unusually deep blue on the face M (010). It occurs in pre-Cambrian gneiss at the Hotchkiss mine, associated with pyrrhotite and pyroxene. The crystals are limpid and free from inclosures, as seen under the microscope, and the opalescence is due to the cleavage on OP (001). It extinguishes in plates cut parallel to M at $+14^{\circ}\ 21'$, and is thus an albite.

1895. **Albite replaced by quartz.** Tyringham (Sodom).

Pre-Cambrian. See page 52 for a description and illustration of this remarkable pseudomorph, which retains the twin striation and pearly luster with great perfection.

ALLANITE.

1852. **Gadolinite.** Becket.

C. U. Shepard: Treat. Min., p. 253. This is probably the allanite from the pre-Cambrian gneiss.

1876. **Allanite.** Becket.

C. U. Shepard: Cat. Min. within 50 miles of Amherst, p. 7.

1890. **Allanite.** Becket. Hinsdale. Dalton. Washington. Otis. Tyringham. Sandisfield.

Allanite is everywhere found in scattered crystals of small size in the Washington (pre-Cambrian) gneiss. Its small pitch-black crystals, with dark reddish decomposition borders and the slight puckering of the fracture in the inclosing gneiss which radiates from each crystal, are very characteristic of the rusty pre-Cambrian gneisses. The best localities are on the brook south of the Dalton clubhouse and opposite D. Clark's house in Tyringham.

AMPHIBOLE.

1823. **Asbestos.** Windsor (near Cummington soapstone quarry).
Asbestos adhering to actinolite.
J. Porter: Min. Loc., Am. Jour. Sci., Vol. VII, p. 252.

1824. **Black hornblende.** Washington.
Well crystallized.
J. Porter: Am. Jour. Sci., Vol. VII, p. 253.

1824. **Tremolite.** New Marlboro.
E. Hitchcock: Geol. of a part of Mass., Am. Jour. Sci., Vol. VIII, p. 35.

1824. **Tremolite.** New Marlboro. Pittsfield. Lee.
New Marlboro; Pittsfield; in dolomite, bladed, granular.
Lee; fibrous, fibers more than 2 feet long.
C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 46.

1825. **Tremolite.** Lee.
Above cited.
S. Robinson: Cat. Am. Min., p. 55.

1825. **Tremolite.** New Marlboro.
S. Robinson: Cat. Am. Min., p. 63.

1825. **Actinolite.**
(The article under 1823, above, is cited.)
The actinolite is found in the north part of the town in large, elegant crystals, which are fasciculate, radiate, or intermixed (J. Porter).
S. Robinson: Cat. Am. Min., p. 77.

1825. **Hornblende.** Dalton.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1828. **Hornblende.** Dalton. Becket.
Rock var. slate. East part of Becket, granitic.
Amos Eaton: Geological Nomenclature, Am. Jour. Sci., Vol. XIV, p. 145.

1832. **Hornblende.** Litchfield County, Connecticut. Sheffield and Great Barrington, Massachusetts.
White crystals, more than an inch long and three-fourths of an inch wide, but much flattened, abound throughout the dolomite of Litchfield County, Connecticut, particularly at Canaan; they are also found under similar circumstances farther north into the borders of Massachusetts, at Sheffield and at Great Barrington.
C. U. Shepard: Treat. Min., Vol. I, pt. 2, p. 266.

1841. **Tremolite.** Tyringham. Lee.
In dolomite.
E. Hitchcock: Final Rept., 585.
No. 537, Catalogue of State collection, p. 809.

1844. **Actinolite.** (*Augitus proteus.*) Windsor.
J. D. Dana: Sys. Min., 2d ed., p. 439.

1844. **Tremolite.** (*Augitus proteus.*) Lee (east part).
Excellent specimens.
J. D. Dana: Treat. Min., 2d ed., p. 371.

1858. **Tremolite.** Becket (southeast part).
Dolomite with tremolite. E. Hitchcock: No. 187 under limestone in Sixth Ann. Rept. Bd. Agri. Mass., Appendix, p. xxxv. Large masses of loosely aggregated and coarse-bladed tremolite, probably from the south end of the Coles Brook pre-Cambrian limestone.

1868. **Actinolite.** Windsor. Lee.
Specimen from Lee is radiated.
J. D. Dana: Sys. Min., 5th ed., p. 241.

1868. **Tremolite.** Lee (1½ miles southwest of meetinghouse).
Idem, 5th ed., p. 241.

1892. **Actinolite.** Windsor. Lee.
Specimen from Lee is radiated.
J. D. Dana: Sys. Min., 6th ed., p. 1060.

1892. **Tremolite.** Lee.
Cited as in 1868.
J. D. Dana: Sys. Min., 6th ed., p. 397.

1894. **Tremolite.** Lee.
In Stockbridge limestone. In separate blades and in long radiate sheaves. The bladed type was abundant in the old Gross quarry and went down to a great depth, spoiling a large quantity of stone. Specimens are found in every collection.

1895. **Asbestos.** Lee.
In Stockbridge limestone. As felted paper-asbestos in thin white sheets several inches across and as fibrous radiated masses near the Hobbs place in South Lee. D. Clark collection.

1895. **Tremolite.** Tyringham (Sodom, below Hop Brook gorge).
In broad, radiate, columnar masses as large as one's fist, made up of pale greenish gray needles 2 to 3 inches long derived from white pyroxene. Also in finest needles shooting through limpid quartz. Pre-Cambrian. D. Clark collection.

1895. **Tremolite.** Monterey (Bear Mountain).
In pre-Cambrian. Straight, fibrous, pale-green to white asbestos fibers 3 to 4 inches long. D. Clark collection.

1895. **Actinolite.** Tyringham (Hop Brook gorge).
In pre-Cambrian limestone. Black to dark-green actinolite in matted blades grown through orthoclase, and broad parallel-bladed masses several inches in length, making very beautiful specimens. It grows around wernerite and causes the bending of the crystals. D. Clark collection.

1895. **Hornblende.** New Marlboro (on road to Southfield, at deep excavation by roadside, in the very rusty rock).
Pre-Cambrian. Cavities are filled with black hornblende crystals 1½ inches long; bladed, well terminated, simple forms. D. Clark collection.

1895. **Hornblende.** Monterey (Bear Mountain).
Pre-Cambrian. In green, massive hornblende rock, fine, stout, black crystals ∞P (110), $\infty P\breve{\infty}$ (010), $\infty P\infty$ (100), P (111), OP (001).

1895. **Tremolite.** Tyringham (the Cobble).
Fine, radiating sncw-white tremolite in the Stockbridge limestone at the foot of the mountain. D. Clark collection.

1895. **Hornblende.** Tyringham (the Cobble).
Pre-Cambrian. Fine jet-black crystals in the garnet biotite rock, with ilmenite above the limestone. D. Clark collection.

1896. **Actinolite.** Becket (one hundred rods east of R. Alderman and son's house).
In the Hinsdale (pre-Cambrian) limestone in large, pale-green, compact masses and in loosely interwoven aggregates of coarse blades of rich green color shading to brown.

1896. **Actinolite.** Otis.

The coarse pre-Cambrian limestone at Otis Center contains an emerald-green bladed actinolite with scapolite.

1896. **Hornblende.**

A black fibrous hornblende is an abundant constituent of the Lee gneiss (p. 33), and of the amphibolites which occur in the Becket gneiss.

APATITE.

1841. **Phosphate of lime.** Hinsdale.

In mica-schist. E. Hitchcock: Final Report of Geol. of Mass., p. 604.

1844. **Apatite.** (*Fluellus hexagonus.*) Hinsdale.

J. D. Dana: Sys. Min., p. 238.

1868. **Apatite.** Hinsdale.

Sparingly. Idem, 5th ed., p. 553.

1892. **Apatite.** Hinsdale.

Idem, 6th ed., p. 767. This locality can not be recovered.

1895. **Apatite.** Tyringham (Sodom, below Hop Brook gorge.)

In pale-green hexagonal prisms half an inch long in white orthoclase, from the Hinsdale (pre-Cambrian) limestone. D. Clark collection.

ARAGONITE.

1895. **Aragonite.** New Marlboro (road to Southfield, at a deep cut in rusty rock by roadside).

In pre-Cambrian rocks, but of late formation. In fine tufted masses of yellow crystalline blades and needles. D. Clark collection.

BARITE.

1890. **Barite.** Becket (east of Shaw Pond).

Bowlders from the Hinsdale (pre-Cambrian) limestone, with galena a chalacopyrite. In bladed masses.

BERYL.

CALCITE.

1814. **Elastic marble.** Pittsfield.

"On taking up one of these stones, from a quarry near Pittsfield, which was just prepared for a gravestone, about 4 feet high and 2 feet wide, I was much surprised at the tremulous motion which I perceived." It bent with the least pressure, but recovered itself without the smallest change or crack. Only a few specimens were elastic. They were grayish white, foliated, granular, and effervescent.

W. Meade: Mineralogical notice respecting elastic marble from Massachusetts.

A. Bruce: Am. Min. Jour., Vol. I, p. 93.

1814. **Elastic marble.**

A polished slab 2 feet long and 1 inch thick, dried near the fire, lost its elasticity, which was immediately restored by wetting. Wm. Meade: letter.

Am. Min. Jour., Vol. I, p. 267.

1832. **Limestone.** New Marlboro.

Gray, CaCO3, 98 per cent; residue, chiefly mica, 2 per cent marble. Abundant; production cited from Dewey. Mill for sawing in New Marlboro.

E. Hitchcock: Geol. Mass., Am. Jour. Sci., Vol. XXII, pp. 26, 38.

1895. **Calcite.** Lee.

In Stockbridge limestone. In a rare geode cavity and perched upon fine dolomite rhombs (see under Dolomite), is a beautiful crystal half an inch long, having the faces R (10$\bar{1}$1), rounded by $\frac{1}{4}R^3$ (21$\bar{3}$4) and $-\frac{1}{4}R$ (01$\bar{1}$2), R (10$\bar{1}$0), R^5 (32$\bar{5}$1), R^3 (21$\bar{3}$1).

D. Clark collection.

1895. **Marble.** Tyringham.

Bowlders. White marble, gray banded marble, black faulted marble.

D. Clark collection.

1895. **Stalactite.** Tyringham (the Cobble).

In the Stockbridge limestone

D. Clark collection.

1895. **Calcite.** Tyringham (Hop Brook).

Pre-Cambrian; very coarse crystalline vein stones, fine gray, pink, plum color, and white; shot through with hornblende crystals, crusted with limpid calcite crystals ∞ R (10$\bar{1}$0), $-\frac{1}{4}R$ (01$\bar{1}$2), 4R (40$\bar{1}$1).

CHABASITE.

1895. **Chabasite.** Tyringham (Hop Brook gorge).

In pre-Cambrian limestone. Massive and in rhombohedra R (10$\bar{1}$1), $-\frac{1}{4}R$ (01$\bar{1}$2), with polished faces 5 mm. across. Green actinolite is intergrown with it. Twins; twinning plane=R. Nearly opaque white.

D. Clark collection.

CHALCOPYRITE.

1890. **Chalcopyrite.** Becket (east of Shaw Pond).

In bowlders from pre-Cambrian limestone with galena and barite.

1893. **Chalcopyrite.** Becket (east of Center Pond on farm of M. J. Alderman).

Vein worked 1 inch wide. Associated with pyrite, pyrrhotite, and calcite in hornblendic gneiss of pre-Cambrian age.

CHONDRODITE.

1841. **Augite.** Lee.

"Within 2 miles of Lee we meet with limestone which often contains a mixture of augite, and this mineral being decomposed at the surface yet projecting beyond the limestone the whole rock exhibits a brown, very irregular aspect."

E. Hitchcock: Final Rept., p. 627.

1885. **Chondrodite.** Hinsdale. Monterey.

Noted as occurring in limestone at the Hinsdale railroad station and in bowlders between South Lee and Monterey.

J. D. Dana: Am. Jour. Sci., Vol. XXIX, p. 208.

1887. **Chondrodite.** Hinsdale. Lee.

Hinsdale; in village (on railroad) and southwest of the village, west of the railroad.

East Lee; on the high hill between the two valleys coming in from the east, in masses as large as one's fist; also on the opposite side of the valley to the northwest, and in the bottom of the valley a mile east of East Lee.

J. D. Dana: Am. Jour. Sci., Vol. XXXIII, pp. 275, 276.

1892. **Chondrodite.** Lee.

In crystalline limestone in East Lee.

J. D. Dana: Sys. Min., 6th ed., pp. 1059, 541.

1895. **Chondrodite.** Becket. Middlefield.

100 rods east of R. Alderman and son's house, in Becket Center, in [illegible] Hinsdale pre-Cambrian limestone band 5 rods wide.

It occurs in red grains, and is especially abundant in a large bowlde[illegible] 100 rods northeast of the ledge. Also in Coles Brook, across Becket an[illegible] Middlefield, especially at the cut at the mouth of Coles Brook, where it i[illegible] changed to pale-yellow serpentine.

1895. **Chondrodite.** Hinsdale. Tyringham. Lee.

In especially large masses, of dark red color, partly changed to chlori[illegible] at O. Bill's, by the roadside, a half mile north of Muddy Pond, in Hin[illegible] dale, and on the high, bare hill east of the hotel at East Lee.

CLINOCHLORE.

1895. **Clinochlore.** Tyringham. Great Barrington.

On Bear Mountain, in matted scales half an inch across, with garnet on a fine-grained biotite-gneiss of pre-Cambrian age.

CYANITE.

1896. **Cyanite.** Becket.

Gray blades, containing small, regular garnets, centrally filled with dark grains, and changing to muscovite. See Pl. I, p. 26.

DOLOMITE.

1821. **Dolomite.** Lee.

Is fetid. Most of that called limestone in the county is dolomite.

C. Dewey: Am. Jour. Sci., Vol. III, p. 239.

1824. **Dolomite.** Lee. Pittsfield. New Marlboro.

In latter place contains augite as well as tremolite.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 35.

1825. **Dolomite.** New Marlboro.

With augite and tremolite.

E. Hitchcock: Geol. of part of Mass., Am. Jour. Sci., Vol. VIII, p. 35.
S. Robinson, Cat. Am. Min., pp. 55, 63.

1854. **Dolomite with tremolite.** Becket (southeast part).

E. Hitchcock: Sixth Ann. Rept. Mass. Bd. Agri., Appendix, p. xxxv, No. 187.

Contains much rather fine-bladed tremolite; is probably from a bowlder of the Stockbridge limestone.

1876. **Dolomite.** Hinsdale. Lee. Lenox. Stockbridge.

C. U. Shepard: Cat. Min. found within 50 miles of Amherst, p. 3.

1895. **Dolomite.** Lee.

In a large drusy cavity from the quarry in the village, in Stockbridge limestone. Rhombs up to an inch on a side, and in other cavities up to 3 inches. Perfectly limpid, and with polished and perfect faces, piled loosely on each other. Some of the rhombs are expanded to broad, flat plates. In others are phantom crystals, containing eccentric, smoky kernels; that is, on a smoky translucent rhomb, half an inch across, is a regular transparent increment two-sixteenths to three-sixteenths inch thick, which is applied only to the three faces adjacent to a lateral solid angle. A complex rhombohedral crystal of calcite half an inch long (see under Calcite) is perched upon one of the rhombs, making a cabinet specimen of rare beauty.

D. Clark collection.

EPIDOTE.

1825. **Epidote.** Windsor.

In prismatic crystals in quartz, also granular in hornblende rocks (H. M. Wells).

S. Robinson: Cat. Am. Min., p. 77.

1825. **Epidote.** Dalton.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1841. **Epidote.** Hinsdale.

In mica-schist.

E. Hitchcock: Final Rept., p. 606.

1895. **Epidote.**

Epidote is everywhere a characteristic constituent of the Hinsdale gneiss, but it rarely occurs in sufficient quantities and depth of color to form cabinet specimens. The best place to find it in any quantity is in the river, behind the stone mill in Dalton.

FIBROLITE.

1824. **Fibrolite?** Becket (Becket).

Minute fibers, dark, hard, infusible, rare.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 40.

1825. **Fibrolite.**

Cited in Robinson's Catalogue. (I have found no fibrolite in Becket.)

1892. **Fibrolite.** Norfolk, Connecticut.

On Tobey Hill and in bowlders to the south, nodules of feldspar and quartz more or less changed to muscovite and fibrolite. Thin section described mica arranged in twinning planes of feldspar.

Wm. H. Hobbs: Pseudomorphs after feldspar, Am. Geologist, Vol. X, p. 46.

)5. **Fibrolite.** Otis. Sandisfield.

Commencing with Filley Mountain in Otis, fibrolite becomes gradua an important constituent of the pre-Cambrian gneiss across Sandisfi and into Connecticut.

397. **Fibrolite.** New Marlboro. Norfolk, Connecticut.

The nodular gneiss that extends from Campbell Falls in New Marlb to Norfolk Center contains abundant fibrolite in the muscovite nodules

GADOLINITE.

1852. **Gadolinite.** Becket.

C. U. Shepard: Treat. Min., p. 253.
See Allanite.

GALENA.

1896. **Galena.** Becket (east of Shaw Pond).

In bowlders from pre-Cambrian limestone, with barite and chalcopyrite.

GARNET.

1858. **Pyrope.** Sandisfield.

E. Hitchcock: Cat. State Coll., Mass. Agri. Rept., p. 52, No. 161. (I common iron garnet in Tyringham gneiss.)

1895. **Garnet.** Tyringham (pasture of Riverside Farm).

In white mica-schist of Cambrian age, forms ∞ O (110), 202 (112), r red-brown. Also on the Cobble in deep red crystals an inch across biotite.

D. Clark collection.

1895. **Garnet.** Monterey (Bear Mountain).

In coarse, white, shining hydromica-schist. Red crystals nearly th fourths inch across ∞ P (110).

GRAPHITE.

1823. **Graphite.** Hinsdale.

J. Porter: Am. Jour. Sci., Vol. VI, p. 248.

1824. **Graphite.** Hinsdale.

Foliated and granular with augite, nearly slaty, in considerable qu
C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 54.

1824. **Graphite (black lead).** Hinsdale.

With augite, foliated and massive.
C. Dewey: Hist. Berkshire County, p. 197.

1825. **Graphite.**

S. Robinson: Cat. Am. Min., p. 54.

1825. **Graphite.** New Marlboro.

In great abundance.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1825. **Graphite.** New Marlboro.

E. Hitchcock: Geol. of part of Mass., Am. Jour. Sci., Vol. VIII

1825. **Graphite.**

Above cited. S. Robinson: Cat. Am. Min., p. 63.

1832. **Graphite.** Hinsdale.
E. Hitchcock: Geol. Mass., Am. Jour. Sci., Vol. XXII, p. 47.

1833. **Graphite.** Hinsdale. New Marlboro.
E. Hitchcock: Rept. Geol. Mass., p. 395.

1841. **Graphite.** New Marlboro. Hinsdale. Washington (1 mile northeast of deep cut at summit level—Lyman's opening).
E. Hitchcock: Final Rept., p. 240.

1844. **Graphite** (*Plumbago scriptoria*). Washington.
J. D. Dana: Sys. Min., 2d ed., p. 539.

1868. **Graphite.**
Idem, 5th ed., p. 770.

1892. **Graphite.**
Idem, 6th ed., p. 1060.

1895. **Graphite.** Monterey (Bear Mountain).
In pre-Cambrian rock. In large masses on top of Sky Hill, with tremolite in blue-quartz gneiss.
D. Clark collection.

1897. **Graphite.** Hinsdale.
The mineral is everywhere characteristic of the pre-Cambrian gneiss, and openings for mining have been made at three places in the town near the creamery, east of the center; near A. Walkin's house, in coarse salite rock; and in an extensive opening at the mine on the Lyman place above Muddy Pond, east of Washington Station.

HEMATITE.

1890. **Hematite.** Hinsdale.
In masses of imperfect flat crystals associated with fine quartz crystals. Min. Coll. of E. B. Underhill, Hallock Mills, N. Y. Presented to Amherst College, 1888.

1895. **Micaceous iron.** Dalton.
In Cambrian quartzite. An aggregate of warped plates in white quartz.
D. Clark collection.

HEULANDITE.

1895. **Heulandite.** Tyringham (Hop Brook).
Crystals 1 mm. long, implanted on hornblende and showing the faces $\infty P\bar{\infty}$ (010), $-2 R\infty$ (201), OP (001). D. Clark collection.

ILMENITE.

1895. **Ilmenite.** Tyringham (the Cobble).
Abundant in broad plates an inch square in a quartz vein in a biotite garnet rock; also in other quartz veins 2 inches square one-fourth inch thick, in twisted plates; also in a mass from the drift, part of a large crystal 1 inch thick and 4 inches square.
D. Clark collection.

1897. **Ilmenite.** Dalton (Day Mountain).
In a lens of coarse granular orthoclase in a muscovite-gneiss full of needles of black tourmaline. It occurs in broad curved lamellæ half an inch thick. Collected by Mr. B. F. Newell, of Dalton.

JEFFERISITE.

1895. **Jefferisite.** Tyringham (Hop Brook gorge).

The great crystals of black biotite at times change to a pale-yellow jefferisite.

D. Clark collection.

LAUMONTITE.

1895. **Laumontite.** Tyringham (Hop Brook).

White square prisms, 20 mm. long, 3 mm. across, and truncated by the usual oblique face. Abundant, but changing easily.

D. Clark collection.

LIMONITE.

1822. **Compact brown oxide of iron.** Dalton.

Incrusting rocks.

P. Cleaveland: Min., p. 607.

1824. **Fibrous brown hematite.** Hinsdale (southwest of town and 4 miles from Pittsfield).

Cement of conglomerate, often half an inch thick.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 18.

1825. **Fibrous brown hematite.**

Above cited.

S. Robinson: Cat. Am. Min., p. 54.

1825. **Limonite.**

Article cited under 1822.

S. Robinson: Cat. Am. Min., p. 47.

1825. **Iron, compact brown oxide.** Pittsfield.

Breccia, with cement of brown oxide, hematite, and carburet of iron, interstices lined with minute quartz crystals.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

The origin of these limonites cementing the Cambrian breccias is given on page 80.

1828. **Hematite.** Dalton (3 miles south of village).

A. Eaton: Geol. Nomenclature, Am. Jour. Sci., Vol. XIV, p. 150.

1830. **Hematite.** Dalton (3 miles south of village).

A. Eaton: Geological Text Book, p. 34.

1832. **Limonite.** Hinsdale.

At Hinsdale the fibrous variety occurs as a cement to a fragmentary quartz rock.

C. U. Shepard: Treat Min., Vol. II, pt. 1, p. 15.

1838. **Hematite iron ore (limonite).** Tyringham.

Several hundred tons dug in south part of the town.

E. Hitchcock: Econ. Geol., p. 126.

1841. **Brown hematite.** Tyringham.

Several hundred tons said to have been dug in the south part of the town. Indications of extensive beds.

E. Hitchcock: Final Rept., p. 197.

1844. **Brown iron ore** (*Siderus hæmaticus*). Hinsdale.

Cement in quartz rock.

J. D. Dana: Sys. Min., 2d ed., p. 449.

1852. **Limonite.** Hinsdale.
At Hinsdale the fibrous variety occurs as a cement to a fragmentary quartz rock.
C. U. Shepard: Treat. Min., p. 277.

1868. **Limonite.**
Idem, 5th ed., p. 173.

1892. **Limonite.**
Idem, 6th ed., p. 1059.
Cited only in locality list.

MAGNETITE.

1825. **Magnetic oxide of iron.** Windsor.
In octahedra (J. Porter).
S. Robinson: Cat. Am. Min., p. 77.

1841. **Magnetic oxide.** Tyringham.
Vein 4 inches wide in quartz rock on Bear Mountain, near the road to Beartown.
E. Hitchcock: Final Rept., p. 194.

1895. **Magnetite.** Tyringham (the Cobble).
In white Cambrian gneiss, in imperfect crystals an inch across.
D. Clark collection.

MELANTERITE.

1824. **Sulphate of iron.** Tyringham.
In loose earth near Shaker Village.
C. Dewey: Hist. Berkshire County, p. 196.

MICROCLINE.

1895. **Microcline.** Tyringham (south side of Hop Brook Valley).
Large cleavage pieces of flesh color, with fine perthitic banding of albite.
D. Clark collection.

MUSCOVITE.

1822. **Mica.** Hinsdale.
It occurs green (J. Porter).
P. Cleaveland: Min., Vol. II., p. 777.

1822. **Prismatic mica.** Hinsdale.
On the edges of common mica.
C. Dewey: Am. Jour. Sci., Vol. V., p. 399.

1825. **Prismatic mica.**
Above cited.
S. Robinson: Cat. Am. Min., p. 53.

1895. **Muscovite.** Tyringham (the Cobble).
In good crystals.
D. Clark collection.

NATRON.

1824. **Carbonate of soda.** Pittsfield (in springs).
C. Dewey: Geol. of part of Mass., Am. Jour. Sci., Vol. XIV, p. 32.

1825. **Carbonate of soda.**
Above cited.
S. Robinson: Cat. Am. Min., p. 65.

OLIGOCLASE.

1895. **Oligoclase.** Monterey (Bear Mountain).

Starting from a point east of Fernside and going south half a mile up the side of Sky Hill. The crystals occur in a green, massive hornblende rock. They are an inch long, of cubical habit and dark flesh color, and show the faces $\infty P\infty$ (010), ∞'P($1\bar{1}0$), $\infty P'$($\bar{1}10$), $\infty P'\breve{3}$(130), ∞'$P\breve{3}$(1$\bar{3}$0), P_1($\bar{1}\bar{1}0$), P($\bar{1}11$), $2_1P\breve{\infty}$ ($\bar{2}01$), $\frac{1}{2}{}_1P\breve{\infty}$ ($\bar{2}01$), $P\breve{\infty}$ ($\bar{1}01$), $2P_1$($\bar{2}\bar{2}1$). They show a fine striation over all the faces in the zone of b; there is a beautiful blue play of color on $\infty P\infty^1$, like Friedricksvärn oligoclase.

ORTHOCLASE.

1832. **Feldspar.** Middlefield. Becket.

The crystals are often deeply embedded in calcareous spar.

C. U. Shepard: Treat. Min., Vol. I, pt. 2, p. 203.

1895. **Orthoclase.** Becket (100 rods east of R. Alderman and son's).

In pre-Cambrian limestone. In stout opaque-white crystals up to an inch long, some elongate in the direction of the prism and terminated by O (001) and $P\infty$ ($\bar{1}01$), and some having O (001) and $\infty P\breve{\infty}$ (010), forming a square prism terminated by ∞P(110) and $P\breve{\infty}$ ($\bar{1}01$). Shows a fine blue opalescence. The same property appears in the feldspar of the coarse granitoid rock adjoining the limestone at the Coles Brook cutting.

1895. **Orthoclase.** Tyringham (John Winthrop pasture, south side upper Tyringham Valley).

From the pre-Cambrian. A white orthoclase, in good crystals of simple form with pyroxene.

D. Clark collection.

1895. **Orthoclase, var. loxoclase.** Tyringham (one-fourth mile southwest of D. Clark's).

In red-brown forms, resembling those from Hammond, New York. Pre-Cambrian, associated with pyroxene.

D. Clark collection.

1895. **Orthoclase.** Tyringham (Hop Brook gorge).

In pre-Cambrian rocks. Greatly etched crystals in chesterlite form.

D. Clark collection.

1895. **Orthoclase.** Tyringham (Sodom, foot of Long Mountain and Hop Brook gorge).

Drusy surfaces of small crystals, often with limpid ends and rounded faces, also in opaque, well-formed crystals ∞P (110), OP (001), $P\breve{\infty}$ ($\bar{1}01$), $2P\breve{\infty}$ ($\bar{2}01$). Shows fine blue opalescence. Is associated with black, bladed hornblende in Hop Brook, and with white pyroxene and tremolite at the other localities, and is often full of square cavities, from which wernerite crystals have been removed. Pre-Cambrian.

D. Clark collection.

1895. **Orthoclase.** New Marlboro (road to Southfield, at digging in rusty rock by roadside).

Pre-Cambrian. Many fine crystals an inch long, of simple exterior forms ∞P (110), $\infty P\breve{\infty}$ (010), $P\infty$ ($\bar{1}01$), $2P\infty$ ($\bar{2}01$), $\infty P\breve{3}$ (210), P ($\bar{1}11$); fine *blue* opalescence; color, opaque-white.

OPAL.

1825. **Opal, hyalite, cacholong, siliceous sinter.** Dalton.
In masses of hornstone.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1890. **Opal.** Sheffield.
Common opal.
G. F. Kunz: Gems and Precious Stones of the United States.

PHLOGOPITE.

1895. **Phlogopite.** Tyringham (Hop Brook).
In many small crystals in wernerite. In pre-Cambrian limestone.
D. Clark collection.

PYRITE.

1824. **Pyrite.** Lee.
In compact masses.
C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 55.

1825. **Pyrite.**
Above cited.
S. Robinson: Cat. Am. Min., p. 55.

1895. **Pyrite.** Tyringham.
One-fourth mile southwest of Mr. D. Clark's house, at the head of the Tyringham Valley. In vein quartz of pre-Cambrian age. In fine crystals one-fourth inch across, superficially changed to limonite O (111), $\left[\frac{2O\infty}{2}\right]\pi$ (210).
D. Clark collection.
Also in bowlders in village 50 rods west of post-office perfect crystals changing to limonite in a quartz rock full of dolomite, 2 to 3 mm. long $\infty O\infty$ (001), $\left[\frac{2O\infty}{2}\right]\pi$ (210). Also at Sodom, below Hop Brook gorge, in finely polished crystals 1 to 15 mm. across changed to limonite.
D. Clark collection.

PYROLUSITE.

1825. **Manganese.** Pittsfield.
The compact brown oxide, in considerable quantities.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 42.

1895. **Dendrite.** Tyringham (in gorge above Riverside farm).
Beautiful forms in Cambrian quartzite. As they are in the red and black colors, they are in large part iron oxides.
D. Clark collection.

1895. **Pyrolusite.** Monterey (near Bidwell place).
Wavy plumose forms in yellow jasper.
D. Clark collection.

1895. **Dendrite.** Dalton.
Bowlder in white Cheshire quartzite.

PYROXENE.

1824. **Ancite.** New Marlboro.
Rough white crystals in limestone (doubtless white pyroxene).
C. Dewey: Hist. Berkshire, p. 194.
(Manifest misprint for augite.)

1824. **Augite.** Hinsdale.
With graphite.
C. Dewey: Hist. Berkshire, p. 197.

1824. **Augite.** New Marlboro. Hinsdale.
New Marlboro; white four, six, and eight-sided prisms. Hinsdale; with plumbago, greenish gray, brown, yellowish, in crystalline forms.
C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 47.

1824. **Augite.** Hinsdale.
With graphite, as at Ticonderoga.
C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 48.

1825. **Augite.**
Same cited.
S. Robinson: Cat. Am. Min., p. 54.

1825. **Augite.** Pittsfield. Dalton. New Marlboro.
Principally massive.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1825. **Augite.** New Marlboro.
E. Hitchcock: Geol. part of Mass., Am. Jour. Sci., Vol. VIII, p. 35.

1825. **Augite.**
Above cited.
S. Robinson: Cat. Am. Min., p. 63.

1841. **Augite.** New Marlboro. Tyringham.
New Marlboro; green augite in dolomite. Tyringham; white augite in dolomite.
No. 236 Catalogue, p. 809.
E. Hitchcock: Final Rept., p. 569.

1844. **Pyroxene.** (*Augitus diatomus.*) Tyringham.
Cited only under localities.
J. D. Dana: Sys. Min., 2d ed., p. 539.

1852. **Scapolite.**
The canaanite of Hitchcock (from Canaan, Conn.), which is an exceedingly tough, compact, grayish white mineral, and contains sil. 53.36, perox. iron 4.09, alum 10.38, lime 25.80, mag. 1.62, carb. acid 4.0 (99.67)
C. U. Shepard: Treat. Min., p. 178.

1852. **Scapolite.** (Canaanite.) Canaan, Conn.
SiO_2 53.36, FeO 4.09, Al_2O_3 10.38, CaO 25.80, MgO 1.62, CO_2 4, 99.67.
Analysis by S. L. Dana.
C. U. Shepard: Treat Min., p. 178.

1868. **Pyroxene.**
J. D. Dana: Sys. Min., 5th ed., p. 770.

1885. **Pyroxene.** Tyringham.
A white, compact, fibrous pyroxene from Tyringham made a curious white cat's eye.
G. F. Kunz: Precious stones, Mineral Resources U. S. 1883–84, p. 728.

1892. **Pyroxene.**
J. D. Dana: Sys. Min., 6th ed., p. 1059.

1895. **Salite.** Tyringham (on the south side of the valley, a half mile above Clark's).
Large prisms of pale salite, coated, and their interspaces filled with pale-green actinolite, on which are stout, curious quartz crystals, which include

actinolite. They (the quartz crystals) have wavy and rounded faces, and terminate by two or three pyramids.

D. Clark collection.

1895. **Pyroxene.** Tyringham (D. Clark farm).

Bowlders of Stockbridge limestone. The mass contained in great numbers doubly terminated crystals of white pyroxene uniformly 1 inch long, half an inch wide, and considerably flattened by the great development of the orthopinacoid. It has the forms $\infty P\infty$ (100), ∞P (110), $+P$ (111), $-P$ ($\bar{1}11$).

D. Clark collection.

1895. **Pyroxene.** Lee (Upper Goose Pond, near Elwells Rocks).

Pale-green pyroxene in stout crystals with perfect basal parting, 1 inch long, three-fourths inch across.

1895. **Pyroxene.** New Marlboro (road to Southfield, in deep digging in rusty rock by roadside).

Pre-Cambrian. Green crystals an inch square, much cracked and corroded.

D. Clark collection.

1895. **Pyroxene changing into hornblende.** Tyringham (foot of Long Mountain).

Pre-Cambrian. Coarse square prisms an inch across and 2 to 3 inches long, of pale-green pyroxene, project outwardly from the limestone, and green bladed actinolite grows from it so as to spoil the surfaces of the pyroxene.

D. Clark collection.

1895. **Pyroxene passing into tremolite.** Tyringham (a half mile southeast of D. Clark's).

Pre Cambrian. In the same way as above described the whitish green pyroxene prisms appear here corroded and separated into distinct cubical blocks, which are much displaced, and out from the whole surface of the prism grew groups of radiate sheaf-like masses of tremolite, with needles often bent. A secondary green pyroxene, having a broad OP (001) face with—P ($\bar{1}11$) and a second prism, is also developed at this locality.

D. Clark collection.

1895. **Pyroxene.** Tyringham (Hop Brook gorge).

Pre-Cambrian. Deep emerald-green transparent prisms, with perfect basal parting and poor prismatic cleavage. Many twins, twinning parallel to $\infty P\infty$ (100) and reaching 4 inches in length. Other crystals are blackish green and pale green. The following combinations occur:

∞P (110), $-P\bar{\infty}$ (101), OP (001).

∞P (110), $-P\bar{\infty}$ (101), OP (001), $P\bar{\infty}$ ($\bar{1}01$).

∞P (110), $-P\bar{\infty}$ (101), $P\bar{\infty}$ ($\bar{1}01$), $+P$ (111), $-P$ ($\bar{1}11$), 2 P ($\bar{2}21$), OP (001).

Minute, long, square prisms occur in greasy wernerite. Other crystals occur with the first combination above; stout crystals an inch broad and 2 inches long, deep green, with dull etched surface.

D. Clark collection.

1895. **Salite.** Tyringham (Sodom, below Hop Brook gorge).

The finest salite prisms of dull white color and an inch across and 2 to 4 inches long. The base occurs implanted in black, white, and pink quartz, distantly or thickly scattered. They show the perfect basal parting. Often the prisms have been dissolved and the etched fragments sometimes remain in the square cavities in the black quartz, and blades of white tremolite tapestry the walls as if they had been formed from

the dissolved pyroxene. The pyroxene had often been broken and recemented by quartz, so that the cavities had cross partitions of quartz like the tabulæ of a rugose coral. These quartz masses, from which the pyroxene has disappeared, were called by the early geologists mortised rock and thought to be the work of Indians. In the gorge itself occur stout columnar masses of crystals an inch across, which are as large as one's fist. The quartz is pseudomorph after albite. See Pls. II, III, p. 52.

D. Clark collection.

1895. **Salite.** Otis Center.

Bowlder. Coarsely cleaving, with cleavage surfaces several inches across; pale-green to white color.

1895. **Pyroxene.** Becket (100 rods east of R. Alderman's).

In pre-Cambrian limestone in large masses of pale-green, massive, coarse pyroxene rock and in loose aggregates of stout eight-sided prisms with strong prismatic and basal cleavage.

1896. **Augite.** New Marlboro (Cleveland mine).

W. H. Hobbs describes and figures a light-green hornblende which is surrounded and intergrown by a colorless pyroxene ("augite"), the two being orientated. Science, Vol. XX, p. 516.

PYRRHOTITE.

1895. **Pyrrhotite in crystals.** New Marlboro (Hotchkiss and Cleveland mines).

Hotchkiss mine; often an inch long; tapering hexagonal prisms with basal planes. Massive at the Cleveland mine.

1896. **Pyrrhotite.** Becket (M. J. Alderman's place).

In large masses from pre-Cambrian limestone.

1897. **Pyrrhotite.** Dalton (limestone locality on brook south of clubhouse on Day Mountain).

Collected by B. F. Newell.

QUARTZ.

1822. **Granular quartz.** Hinsdale.

It is said to occur in large friable masses, snow white and much resembling sugar. It may prove important in the manufacture of glass and stoneware.

P. Cleaveland: Min., Vol. I, 239. Refers to great bowlders of Cheshire quartzite. Cited 1825 by S. Robinson: Cat. Am. Min., p. 53.

1824. **Quartz.** Lenox. Lee. Hindsdale. Pittsfield. Washington.

Flattened terminated prisms; in quarry at Lenox.

Granular or as sand; everywhere. Yellow and red; Pittsfield, a considerable rock composed almost entirely of small crystals. Chalcedony, yellowish hornstone, cacholong, and opal; Hinsdale. Buhrstone; Washington.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 38. Cited 1825 by S. Robinson: Cat. Am. Min., p. 55.

1824. **Blue quartz, fetid quartz, hornstone.** Lenox. Pittsfield.

Ferruginous quartz, massive and well crystallized, Lenox. Hornstone jasper, generally gray and blue, Pittsfield.

J. Porter: Min. Loc., Am. Jour. Sci., Vol. VII, p. 252.

1824. ***Cacholong, hornstone, chalcedony.*** Hinsdale.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 39.

1825. **Cacholong.**
Before cited.
S. Robinson: Cat. Am. Min., p. 54.

1825. **Yellow ferruginous quartz.** Dalton.
Crystallized and amorphous. J. Porter.
S. Robinson: Cat. Am. Min., p. 47.

1825. **Jasper, hornstone, agate, quartz crystals, ferruginous quartz.** Pittsfield. Dalton. New Marlboro.
Massive and crystallized. Very large agates in masses of hornstone and jaspery quartz and jasper; Pittsfield. Ferruginous quartz in yellow crystals; Dalton.
Arenaceous quartz; New Marlboro.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1825. **Blue quartz.** Windsor.
Of good color in amorphous masses. (J. Porter.)
S. Robinson: Cat. Am. Min., p. 77.

1841. **Chalcedony.** Tyringham.
E. Hitchcock: Final Rept., p. 186.

1841. **Mammillary chalcedony.** Tyringham.
Nos. 2328, 2329 in catalogue of State collection.
(Quartz.)
E. Hitchcock: Final Rept., p. 819.

1854. **Mammillary chalcedony.** Tyringham.
Nos. 236, 237.
E. Hitchcock: Cat. Rocks of Mass., 6th Rept. Mass. Bd. Agri., Appendix, p. 54.

1876. **Quartzite, iron flint.** Hinsdale.
C. U. Shepard: Cat. Min. within 50 miles of Amherst, p. 7.

1890. **Quartz.** Hinsdale.
Large geode cavities, with fine slightly smoky crystals, doubly terminated with very short prisms associated with specular iron.
Coll. of E. B. Underhill, Hallock Mills, N. Y. Presented to Amherst College, 1888.

1890. **Quartz.** Becket (east of Shaw Pond).
Blue chalcedony with drusy surfaces, in bowlders of pre-Cambrian gneiss.

1895. **Amethyst.** Becket (R. Alderman's).
In contact selvage of pre-Cambrian limestone with actinolite, etc.

1895. **Quartz.** Monterey (Bear Mountain).
Pre-Cambrian. In pale smoke-gray crystals, with etched and rounded faces, associated with fine fibrous actinolite and graphite.
D. Clark collection.

1895. **Quartz.** Tyringham (the Cobble).
In well-terminated crystals in a granite vein.
D. Clark collection.

1895. **Rose quartz.** Otis (roadside near east side of Tyringham).
D. Clark collection.

1895. **Yellow jasper.** Tyringham.
In drift; with surface of blue chalcedony. Also a deep liver-red jasper brecciated with white, from bowlder in John Winthrop pasture.
D. Clark collection.

1895. **Chalcedony.** Tyringham (D. Clark farm, one-fourth mile east of house).

Beautiful great masses of translucent chalcedony; flesh color to amber, with small botryoidal surface of bluish or whitish shade.

D. Clark collection.

1895. **Jasper.** Monterey (Marshall Bidwell's land, near Lake Garfield).

Jasper of various shades of yellow, often colored black by manganese and coated by fine drusy quartz; also colored black by manganese and running into fine blue shades, often raised above the general surface in matted masses of finely interlaced threads, as if the quartz had coated rootlets. This is the best locality, but the same jasper is found all up and down the Tyringham Valley in the drift—at Fernside, in Otis, in Becket, where a great mass was blasted in the roadside, and near the West Becket post-office. All these jaspers indicate faults.

D. Clark collection.

1895. **Brown jasper-agate.** Tyringham.

Beautiful botryoidal masses showing white and brown concentric rings from the truncation of the balls.

D. Clark collection.

1895. **Black quartz.** Tyringham (the Cobble and at the foot of the Hop Brook gorge).

A black quartz vein, the mineral often beautifully iridescent from fissuring.

D. Clark collection.

1895. **Cellular quartz.** Tyringham.

Bowlder. A quartz breccia with the pebbles dissolved out. A fault rock probably brought south from the South Dalton fault.

D. Clark collection.

1895. **Fetid quartz (necronite).** Tyringham.

Bowlder.

D. Clark collection.

1895. **Quartz crystals.** Tyringham (Fernside).

Fine limpid crystals half an inch long.

1895. **Greasy quartz.** Lee.

From a bowlder on the old turnpike from Lee to South Lee, one-fourth mile south of the covered bridge. A fine greasy quartz, white and deep leek-green.

D. Clark collection.

1895. **Quartz pseudomorph** after albite and containing salite crystals which are often dissolved or replaced by tremolite. Tyringham (Sodom).

In pre-Cambrian limestone; see page 52 for figures and full description.

1895. **Amethyst.** Tyringham (near Upper Goose Pond).

Of pale color.

1896. **Chalcedony.** Otis Center.

Bowlder. Very large masses of a white chalcedony, which in cavities is fine botryoidal, drusy, and of faint sky-blue color.

It includes angular fragments of a yellow jasper, showing that it is the filling in of a vein in which the yellow jasper had been a previous filling shattered by a later movement of the vein walls. Both contain fragments of the wernerite, which shows that they are fillings of fissures in the calcite bed on the Otis fault.

1896. **Jasper.** Hinsdale.

In large masses on west slope of hill 1,720 feet high, 2½ miles north of station. Also on Peru road north of Ashmere Lake, in yellow, red, and white colors. (Doubtless from Cheshire quartzite.)

Collected by B. F. Newell.

RUTILE.

1825. **Red oxide of titanium.** Pittsfield (southeast part; in green quartz). Dalton (in quartz). New Marlboro.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 42.

1832. **Rutile** (Peritoneous Erythrone-ore). Windsor.

The locality affording rutile in the greatest quantity in the United States is a very extensive ledge of chlorite slate at Windsor, Mass. The crystals of rutile are here thickly disseminated through narrow veins of feldspar traversing this rock, and also occur in seams in the rock itself.

C. U. Shepard: Treat. Min., Vol. II, Pt. I, p. 169.

1844. **Rutile** (*Peritoneous Erythrone-ore*). Windsor.

Fine crystals thickly disseminated through veins of feldspar intersecting chlorite slate.

J. D. Dana: Sys. Min., 2d ed., p. 421.

1852. **Rutile.** Windsor.

C. U. Shepard: Treat. Min., p. 256.

1868. **Rutile.** Windsor.

J. D. Dana: Sys. Min., 5th ed., p. 161.

1876. **Rutilite.** Windsor.

C. U. Shepard: Cat. Min. within 50 miles of Amherst, p. 7.

1881. **Rutile.** Windsor.

In red-brown deeply striated prisms up to 1½ inches long, closely resembling the Chester County, Pennsylvania, variety. In white albite.

1892. **Rutile.** Windsor.

J. D. Dana: Sys. Min., 6th ed., p. 235.

1895. **Rutile.** Tyringham. Dalton (Cottsville quarry).

Bowlder in Stockbridge limestone. Dark red-brown striated needles.

SCOLECITE.

1895. **Scolecite.** Tyringham (Hop Brook gorge).

Radiated blades on orthoclase. In masses of radiated tufts and globules graduating upward into fine globes of 1 inch in diameter of finest fibrous character, also in thick masses so finely fibrous and altered to kaolin that it has a massive porcelaneous look and botryoidal surface, also a soft, drusy surface growth forming great masses of balls an inch across. It also occurs encrusting biotite and pyroxene, and in a later generation with other zeolites. See p. 55.

D. Clark collection.

1895. **Scolecite pseudomorph after wernerite.** Tyringham (Hop Brook).

(See under wernerite.)

D. Clark collection.

SERPENTINE.

1823. **Serpentine.** Windsor (northwest part).

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 50.

1824. **Serpentine.** Windsor.

C. Dewey: Hist. Berkshire County, p. 191.

1824. **Vert antique?** Becket.

A magnesian mineral found in a bed in gneiss on the river in Becket, colored green by serpentine. It may, as Dr. Emmons supposes, be a serpentine marble. It is a tough mineral and takes a fine polish. The quantity of serpentine is sometimes small and the color yellowish white.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 58.

(This is the Coles Brook limestone with altered chondodrite.)

1825. **Vert antique.**

The above localities in Windsor and Becket cited.

S. Robinson: Cat. Am. Min., p. 77.

1825. **Serpentine.** Dalton (east part of town).

Containing asbestos.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1841. **Serpentine.** Windsor (northeast and northwest parts). Cheshire (south of M. House's, a little east of the four corners).

Windsor, northeast part; serpentine with chondrodite. Cheshire; hard serpentine in gneiss.

Catalogue of State collection.

E. Hitchcock: Final Rept., pp. 616, 877, 878.

SPINEL.

1892. **Spinel.** Norfolk, Connecticut.

Spinel is absent in the pre-Cambrian limestones of the Sandisfield and Becket quadrangles, and first appears south of the border of the map in Norfolk in the same limestone.

STAUROLITE.

1822. **Staurolite.** Pittsfield.

In small, light-brown crystals, either single or crossing each other at right angles.

It is associated with garnets and sulphuret of iron (Hall).

P. Cleaveland: Treat. Min., Vol. II, p. 776.

1823. **Staurotide.** Hinsdale.

"In vast quantities in mica-schist." Am. Jour. Sci., Vol. VI, p. 219.

S. Robinson: Cat. Am. Min., p. 53. This is a citation from Hitchcock's Geology of the Connecticut, and refers to Hinsdale, New Hampshire. Hitchcock is giving the list of towns up the Connecticut and crosses the State line without indicating it.

1824. **Staurolite.** Sheffield.

In small area of mica-schist.

C. Dewey: Am. Jour. Sci., Vol. VIII, p. 7.

1885. **Staurolite.**

J. D. Dana: Am. Jour. Sci., 3d ed., Vol. XXIX, p. 214.

STILBITE.

1895. **Sphærostilbite.** Tyringham (Hop Brook).

Pre-Cambrian. In balls with faceted faces, radiated within with pearly luster. Fine groups coating biotite; also in sheaves and in segments of wheels. One beautiful cylindrical mass, 7 inches high, 4½ inches in diameter, covered with the warty protuberances made of the fine spheres, was sent to the exposition at Chicago. One mass more than a foot across was found. There is also a second growth of small, single crystals of stilbite. It occurs also in separate projecting and interlaced thick blades $\infty P \breve{\infty}$ (010), $\infty P \bar{\infty}$ (100), OP (001). Color, opaque-white, often smoky exteriorly. Other crystals appear with tapering ends from the development of P (111). Other specimens are small, limpid, single crystals $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010), OP (001).

The zeolites were found in a rotten vein in the coarse pyroxene rock with big crystals of dark brownish black biotite changed to jefferisite; well-formed crystals 1½ inches to 5 inches across, some often fused together by sphærostilbite and deeply warped.

D. Clark collection.

SULPHUR.

1824. **Sulphur.** Tyringham.

In mica-slate.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 54.

1824. **Sulphur.** Hinsdale.

In cavities of a mica-slate rock consisting chiefly of quartz. It is a brown powder, from its mixture probably with oxide of iron.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 33.

1825. **Sulphur.** Localities in Tyringham and Hinsdale cited above.

S. Robinson: Cat. Am. Min., pp. 54, 73.

I have not found sulphur in the cavities of the Hinsdale gneisses, which are, however, often filled with a yellow pulverulent limonite.

TALC.

1823. **Steatite (potstone).** Windsor.

Very fine; formerly wrought into inkstands, which are still made by Shakers.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 51.

1824. **Talc.** Windsor.

C. Dewey: Hist. Berkshire County, p. 191.

1824. **Steatite.** Windsor.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 51.

1825. **Steatite.**

Cited above. Also talc. (H. M. Wells.)

S. Robinson: Cat. Am. Min., p. 77.

1825. **Talc.** Pittsfield.

Of different colors.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1841. **Steatite.** Hinsdale.

E. Hitchcock: Final Rept., p. 156.

1841. **Steatite.** Hinsdale.

In gneiss.

E. Hitchcock: Final Rept., p. 610.

1892. **Talc.** Hinsdale.

The great beds of talc connected with the Hinsdale limestone are described on pages 28–32. The largest beds are at the quarry near Wakonah Falls, the stratum being 30 feet thick, where the brook from Ashmere reservoir crosses River Bend Farm below the mill pond.

TITANITE.

1824. **Red oxide of titanium.** Pittsfield.

In small prisms in quartz associated with dolomite; rare.
C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 58.

1841. **Sphene.** Lee (east part of town). Tyringham.

Lee; in augitic gneiss; finest in New England; No. 1091, Cat. State Coll., p. 637. In talcose limestone, No. 1981, Cat. State Coll., p. 810.
Tyringham; with hornblende, No. 2301, Cat. State Coll., p. 818.
E. Hitchcock: Final Rept. Geol. of Mass.

1844. **Sphene** (*Rutilus obliquus*). Lee (eastern part).

Very good specimens in gneiss.
J. D. Dana: Sys. Min., 2d ed., p. 422.

1854. **Sphene.** Becket.

In talcose limestone (probably Coles Brook bed).
E. Hitchcock: No. 193, Cat. Mass. Coll., Agri. Rept., p. 35.

1858. **Sphene.** Tyringham.

With hornblende; No. 210.
E. Hitchcock: Cat. Mass. Rocks in 6th Ann. Rept. Mass. Bd. Agri.

1868. **Sphene.**

J. D. Dana: Sys. Min., 5th ed., p. 386.

1872. **Sphene.**

J. D. Dana: Sys. Min., 6th ed., p. 715.
E. Hitchcock: Final Rept. Geol. of Mass.

1895. **Titanite.** Sandisfield. Becket. Coles Brook.

Sandisfield; in drift on Birch Hill, with hornblende and wernerite.
Becket; 100 rods east of R. Alderman's house.
Crystals a half inch long.
Coles Brook; in Hinsdale limestone.

1895. **Titanite.** Tyringham (Sodom, Hop Brook gorge).

In pre-Cambrian limestone. Beautiful flat transparent chestnut-brown crystals, often an inch long. Some are rich red-brown at one end and grade to clove-brown or dusty-white at the other. There are also most beautiful limpid hyacinth-red bladed crystals in calcite. In Sodom chestnut-brown crystals occur in pink calcite with radiating black hornblende. They show the faces OP (001), P ($1\bar{1}1$), $\infty P\infty$ (100), ∞P (110), and multiple twinning according to the third law (Dana) approximately parallel to 221.
D. Clark collection.

1895. **Titanite.** New Marlboro (road to Southfield).

Deep cutting in rusty rock by roadside. Pre-Cambrian. Large pale-brown wedge-shaped crystals.
D. Clark collection.

1895. **Titanite.** East Lee (east of the Gousset road).

Bowlder of pre-Cambrian Hinsdale limestone.
The crystals are half an inch long and of pale Isabella yellow. Forms: OP (001), $\infty P\infty$ (100), ∞P (110), P (111).
D. Clark collection.

1895. **Titanite.** Becket (near West Becket post-office).

A large mass was blasted out in improving the road. The mineral occurs in a white, granular feldspar rock (pre-Cambrian), with green actinolite, and is probably from an altered form of the Hinsdale limestone. It is in very abundant crystals of rich chestnut color, often an inch long, and shows the forms OP (001), P (111), ∞ P (110).

D. Clark collection.

1895. **Titanite.** Otis (Hop Brook gorge).

From the upper bed of pre-Cambrian limestone. Flat-bladed chestnut-brown crystals an inch long.

D. Clark collection.

TOURMALINE.

1821. **Schorl.** Dalton. Pittsfield (southeast part of the town).

In mica-slate.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 42.

1822. **Yellow tourmaline.** Dalton (near the Housatonic).

In groups of straw-yellow crystals from an inch to 2 inches long, sometimes with terminations in granular limestone (M'Euen).

P. Cleaveland: Min., p. 321.

This interesting occurrence I have not been able to verify. It may be tremolite in the Stockbridge limestone, but from the great abundance of minute tourmaline in the subjacent Cheshire quartzite the occurrence of tourmaline in the limestone is not improbable.

1824. **Black tourmaline.** Washington.

J. Porter: Min. Loc., Am. Jour. Sci., Vol. VII, p. 252.

I have not found this mineral in Washington.

1825. **Yellow tourmaline.** Dalton (near the Housatonic).

In groups of straw-colored crystals in granular limestone.

S. Robinson: Cat. Am. Min., p. 46.

1895. **Tourmaline.** Sandisfield (in field near Mr. George Blake's house).

Black crystals 1 inch across and 3 to 5 inches long, in a small pegmatite vein, much jointed, faulted, and recemented into beautiful series of echeloned disks.

1895. **Tourmaline.** Tyringham (the Cobble).

In well-terminated black crystals in a granite dike.

D. Clark collection.

1895. **Tourmaline.** Sandisfield (near town hall).

Black crystals 1½ inches across, much jointed, and recemented with quartz.

D. Clark collection.

WERNERITE.

1841. **Scapolite.** Tyringham. Lee.

Tyringham; crystallized hornblende and scapolite; No. 2300, State collection.

Lee; augite with scapolite; No. 1092, State collection.

E. Hitchcock: Final Rept. Geol. of Mass., p. 818.

1844. **Scapolite.** (*Scapolus pyramidalis.*) Tyringham.
J. D. Dana: Sys. Min., 2d ed., p. 539.

1858. **Scapolite.** Tyringham.
With hornblende.
E. Hitchcock: No. 218, Cat. Rocks of Mass., 6th Ann. Rept. Mass. Bd. Agri.

1868. **Scapolite.**
J. D. Dana: Sys. Min., 5th ed., p. 770.

1892. **Scapolite.**
Idem, 6th ed., p. 1059.

1895. **Wernerite.** Tyringham (Hop Brook gorge, Sodom).
Pre-Cambrian. Pure white prisms 2 inches long and 1 inch square. Other crystals in almost acicular square prisms; crystals generally bent or broken by later growth of hornblende.
D. Clark collection.

1895. **Wernerite.** Lee (Upper Goose Pond, near Elwells Rocks).
Peculiar forms; deep topaz to flesh-colored; glassy and highly lustrous on crystal faces; transparent, and a true gem form. Some crystals broken. The crystals are black at base and change up through brown and wine-yellow to nearly colorless. Inset crystals raised from the polished faces. The $\infty P \infty$ (101) cleavage is perfect; crystals are half an inch wide and 1 inch long, with the form $\infty P \infty$ (101), P (111).
Masses 2 inches square show deep flesh-color; more fibrous cleavage, like ordinary scapolite; growing paler by alteration. Blades of deep-green actinolite and pyroxene prisms are grown through the mass.
Also large masses of coarse granular texture composed of imperfect stout crystals 1 inch across, bluish gray shading to white at border, and very fresh, greasy luster, with biotite.
D. Clark collection.

1895. **Wernerite changing into scolecite.** Tyringham (Hop Brook gorge).
Large imperfect square prisms, with greasy bluish luster, and masses of a colorless wernerite granular rock, full of small phlogopites and actinolite blades, are changed to a mass of radiated fine fibrous balls of scolecite, opaque white, at the surface forming delicate botryoidal surfaces of the fine free needles. In cross sections the balls are concentrically banded, the lower half opaque-white, the upper translucent. This wernerite is found in masses of tons in size along the brook gorge, white and pale gray, with crystals growing from the surface. Other crystals are small square prisms one-half inch long, one-fourth inch wide, often bent; snow-white, with satiny luster, apparently changed to scolecite in needles parallel to OP (001). Other specimens are also coated with the radiated balls of scolecite as above. One piece bristles with white needles of wernerite one-half millimeter across, many of which are deep square hollows, leaving only shells, and many are inclosed in deep-green pyroxene and remain hollow.
D. Clark collection.

1895. **Wernerite.** Tyringham (Hop Brook).
A large impure crystal, full of calcite and phlogopite, was examined in thin section under the microscope. The crystal is full of minute, long, square prisms, whose cleavage, high relief, and oblique extinction show them to be white pyroxene. The wernerite is brown, shaded in irregular *patches*, which are white by reflected light. This is caused by the fibrous

decomposition product common in wernerite, which is optically positive and has very weak double refraction (V = .008), agreeing exactly with scolecite. A twinning suture runs parallel with OP (001), and the optical axis makes an angle of 16° with this on either side.

1895. **Wernerite.** Sandisfield (Beech Plain).

In drift, with hornblende and titanite.

1895. **Wernerite.** Otis (Otis Center).

The coarse limestone at Otis Center contains wernerite in groups of stout, white, interlaced crystals and purple glassy masses. It occurs in the brook bed near the mill and just west of the village street.

ZOISITE.

1841. **Zoisite.** Hinsdale.

In mica-schist.

E. Hitchcock: Final Rept., 606.

(I have never seen zoisite from Hinsdale. It may be the same mineral cited herein as fibrolite.)

1844. **Zoisite.** (*Carbunculus rhomboideus.*) Hinsdale. Windsor.

J. D. Dana: Sys. Min., 2d ed., p. 300.

1868. **Zoisite.**

Idem, 5th ed., p. 292.

1892. **Zoisite.**

Idem, 6th ed., p. 514.

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1734. WINTHROP (John). Selections from an ancient catalogue of objects of natural history found in New England more than a hundred years ago, by John Winthrop, F. R. S., from the Journal Book of the Royal Society, Vol. XV, p. 451. (Manuscript.) Am. Jour. Sci., Vol. XLVII, p. 282, 1824.

1809. MACLURE (W.). Observations on the geology of the United States, with geological map. Trans. Am. Philos. Soc., Vol. VI, pp. 411, 428.

1814. MEADE (W.). Mineralogical notice concerning elastic marble from Massachusetts. A. Bruce, Am. Min. Jour., Vol. I, pp. 93, 267.

On taking up one of these slabs it was found to be so completely elastic that the writer feared it would fall in pieces before he could replace it.

1816. CLEAVELAND (Parker). Elementary treatise on mineralogy and geology, with colored geological map of the United States; 668 pages.

The map was taken from Maclure. Berkshire County is colored as "Primitive."

1818. EATON (Amos). An index to the geology of the northern States, with a transverse section from the Catskill Mountains to the Atlantic, prepared for the geological classes at Williams College, Northampton, Belchertown, Leicester, and Worcester (Massachusetts).

The section gives, although crudely, the Hinsdale anticline, but makes its core granite instead of gneiss, and identical with the much later granite of Chesterfield. On this granite rest the "granular limestone" and quartz. This is the Hinsdale limestone, and it is clearly separated from the newer "metalliferous limestone" to the west, the latter being the Stockbridge limestone (p. 84).

Next above this is the gneiss, which "sinks laterally under the mica-schist to the west, and probably does not rise again until it reaches the continent of Asia." Above this is the mica-slate, "the calcareous and granular quartz," the "soapstone rocks," including the hydromica-schists, as well as the steatite and serpentine, and lastly the "syenite." By this is meant the Chester and Hawley amphibolites, and he notes the spotted or "porphyritic" varieties in Hawley. This bed is said to cap the series east of Dalton, and "therefore all the tract is 'Primitive.'"

1818. MACLURE (W.). Observations on the geology of the United States, with map. Trans. Am. Philos. Soc., n. s., Vol. I, p. 1.

1820. EATON (Amos). An index [etc.]; 2d edition.

"Written over anew."

1820. ——— Localities of minerals, from the minutes of the Troy *Lyceum*. Am. Jour. Sci., Vol. II, p. 238.

1821. DEWEY (C.). Fetid dolomite found in Lee; found by analysis to be magnesia. Am. Jour. Sci., Vol. III, p. 239.

1822. CLEAVELAND (Parker). An elementary treatise on mineralogy and geology. Second edition, 2 vols. With copy of W. Maclure's geological map, from work cited above, 1818.

1822. DEWEY (C.). Prismatic mica (Hinsdale). Am. Jour. Sci., Vol. V, p. 399.

1823. PORTER (Jacob). Localities of minerals. Am. Jour. Sci., Vol. VI, p. 246.

1823–6. Boston Journal of Philosophy and the Arts. J. W. Webster, editor. 3 vols.

Catalogues of minerals from several localities.

1824. A history of the county of Berkshire, Mass. By gentlemen of the county, clergymen, and laymen. Colored geological map.

Geology by Prof. Chester Dewey. The central gneiss mass, with soapstone and serpentine, is mentioned. The quartzite and the limestone are said to extend south in two bands; the western, from Adams to Cheshire, is the Stockbridge limestone; that from Windsor to New Marlboro is pre-Cambrian.

1824. HALL (F.). Catalogue of minerals.

1824. PORTER (Jacob). Localities of minerals. Lenox, Pittsfield, Washington. Am. Jour. Sci., Vol. VII, p. 252.

1824. DEWEY (Chester). A sketch of the geology and mineralogy of the western part of Massachusetts, and a small part of adjoining States. Am. Jour. Sci., Vol. VIII, pp. 1–60. Geological map.

The first connected account of the geology of Berkshire County. All the upland country mapped in this study is assigned to mica-slate except a band of gneiss along the Peru line and a broad band of primitive limestone which runs down across Hinsdale and Washington and is given the same color as the valley limestone. The quartzite is the only other rock distinguished upon the map.

1824. ———. Additional remarks on foregoing. Am. Jour. Sci., Vol., III p. 240.

1825. LEE (Charles A.). Notice of minerals in Pittsfield and Dalton. Am. Jour. Sci., Vol. IX, pp. 42, 43.

1825. ROBINSON (Samuel). A catalogue of American minerals, with their localities. Boston.

Quotes minerals from Becket, Dalton, Hinsdale, Lee, Lenox, New Marlboro, Pittsfield, and Windsor.

1830. EATON (Amos). Geological text-book. Albany.

Southeastern Berkshire is mapped as follows: limestone from the west up to the Housatonic; quartzite east of this to Franklin and Hampshire counties; in the southeastern corner is primitive, interrupted by a band of limestone entering from Litchfield County.

1830. A history of the county of Berkshire, Massachusetts, in two parts; the first being a general view of the whole county; the second an account of the several towns, by gentlemen of the county, clergymen, and laymen. Geographical and geological map.

Geological part by Prof. Chester Dewey.

1832. HITCHCOCK (E.). Report on the geology of Massachusetts, examined under the direction of the government of that State during the years 1830 and 1831 by Edward Hitchcock, professor of chemistry and natural history in Amherst College. Part I. The economical geology of the State, with a geological map. Am. Jour. Sci., Vol. XXII, p. 1.

1832. SHEPARD (C. U.). Treatise on mineralogy. 2 vols. New Haven.

1835. HITCHCOCK (E.). Second edition of above report on geology of Massachusetts, 1832.

1838. ——— Report on the reexamination of the economical geology of Massachusetts.

Notice of the limonite.

1841. ——— Final report on the geology of Massachusetts. 4°. 831 pp., plates and map.

1842. PERCIVAL (J. G.). Report on the geology of the State of Connecticut, with geological map. 495 pp. 8°. New Haven.

Format'on L (limestone) K_2 (gneiss) are extended into Massachusetts.

1842. EMMONS (E.). Geology of New York, 2d district. 4°.

The discussion of the Taconic system extends into this region, under "Granular quartz," p. 158.

1842. MATHER (W. W.). The geology of New York, 1st district.

All the limestones of western Massachusetts are said to be altered Lower Silurian, pp. 464, 476, 542.

1844. DANA (J. D.). System of mineralogy. 2d edition.

1844. HITCHCOCK (E.). Geological map of Massachusetts on the topographical map by E. Borden. Explanation of the above map, separate pamphlet. 8°. 22 pp. Boston.

1845. LYELL (C.). Travels in North America.

"The opinion of Professor Hitchcock and H. D. Rogers that the Taconic Range is altered Silurian appears to me highly probable." P. 195.

1852. SHEPARD (C. U.). A treatise on mineralogy. 3d edition. New Haven.

1853. MARCOU (J.). Geological map of the United States, with explanatory text. Boston.

See Bull. U. S. Geol. Survey No. 127.

1853. HITCHCOCK (E.). Outlines of the geology of the globe and of the United States in particular, with map.

Area made hypozoic and metamorphic.

1854. HUNT (T. S.). On the crystalline limestones of North America. Am. Jour. Sci., 2d Ser., Vol. XVIII, p. 195.

All the limestones of western Massachusetts are Lower Silurian; the Archean limestones considered to be only more metamorphosed portions.

1855. MARCOU (J.). Ueber die Geologie der Vereinigten Staaten, mit Karte.

Makes the whole area granite and metamorphic rock.

1855. EMMONS (E.). American geology.

Gives Greylock section of "Taconic rock" and explains the iron breccia as igneous.

1858. WALLING (H. F.). Map of the county of Berkshire, based upon the trigonometric survey of the State. The details from actual surveys under the direction of Henry F. Walling.

1858. HITCHCOCK (E.). Geological map of Berkshire County.

On the above topographical map.

1859. ——— Agricultural museum catalogue of collection of rocks, minerals, and fossils in the State cabinet, obtained during the geological surveys of the State by Dr. Edward Hitchcock, with later additions. Appendix 6th Ann. Rept. of Board of Agriculture. Boston: State printer.

Collection in State capitol many years, then in Agricultural College, Amherst; thrown in confusion by a fire and not rearranged. Duplicate collection in Amherst College.

1866. HALL (J.) and GAGAN (W. E.). Geological map of Canada and the adjacent region, 1866.

The Stockbridge limestone is made Levis's 5a, in Quebec group, and the Hoosac schists are Sillery (6); all the rest Lauzon 56.

1868. DANA (J. D.). System of mineralogy. 5th edition.

1868. PERRY (J. B.). Life of E. Emmons. Proc. Boston Soc. Nat. Hist., Vol. XII, p. 214.

1871. HITCHCOCK (C. H.). Geological description of Massachusetts, with geological map. Walling's Atlas of Massachusetts, p. 17.

Eozoic are "the gneissic rocks of the Hoosac Mountain Range, which have anticlinal structure." The quartz rock is the lower Potsdam of Billings. The Stockbridge limestone is Levis group of Canada. The Berkshire schist is "Lauzon" of Canada, and all those parts of the Quebec group above the Chazy are Sillery. The "Talcose schist" (Hoosac and Rowe schists) are also Quebec. The Middlefield and Rowe serpentines (that is, in effect, the Chester series) are the equivalent of the limestones in the schists of the Taconic Range. The map, by the inexcusable blundering of the colorist, is wholly worthless, and was repudiated by its author at the Boston meeting of the American Association for the Advancement of Science.

1871. CREDNER (H.). Die Geognosie und der Mineralreichthum des Alleghany-Systems. Petermann's Mittheilungen, 1871, p. 41.

Makes the Berkshire Valley Huronian, the highlands Laurentian.

1872. DANA (J. D.). Green Mountain geology. Am. Jour. Sci., 3d series, Vol. III, pp. 179, 250.

On the quartzite.

1872. DANA (J. D.). On the quartzite, limestone, and associated rocks of the vicinity of Great Barrington, Berkshire County, Mass. Am. Jour. Sci., 2d series, Vol. IV, pp. 362, 450.

1873. ——— Same, Vol. V, pp. 47, 84; Vol. VI, p. 257.

1873. HITCHCOCK (C. H.) and BLAKE (W. P.). Geological map of the United States.

The hill country on the east is assigned to the Eozoic; the western valley to the Silurian.

1875. BRADLEY (F. H.). A geological chart of the United States.

The whole of Berkshire County is made Lower Silurian.

1876. SHEPARD (C. U.). Catalogue of minerals found within 75 miles of Amherst College. Privately printed May 20, 1876.

The greater number are found within 50 miles of this center.

1876. CROSBY (W. O.). Report on the geological map of Massachusetts, prepared for the Centennial Exposition at Philadelphia. Boston. 52 pp.

Noticed, probably by J. D. Dana, in Am. Jour. Sci., 3d series, Vol. XII, p. 459, where the statement that the Berkshire limestones and associated rocks are older than the Primordial is criticised and the Lower Silurian fossils found in Vermont are adduced.

1877. DANA (J. D.). On the relations of the geology of Vermont to that of Berkshire. Am. Jour. Sci., Vol. XIV, pp. 37, 132, 202, 257.

1877. HITCHCOCK (C. H.). Geology of New Hampshire. 3 vols. Atlas in folio.

Vol. II, p. 8, Pl. I, assigns the valley to the Silurian and Cambrian; Bear Mountain and the area south across Monterey, New Marlboro, and Norfolk to the Laurentian; and the broad area of the Cambrian gneisses to the east of these subdivisions to the "Atlantic"—a subdivision of the Archean between the Laurentian and the Huronian.

1879. ——— Macfarlane's railroad guide.

This gives Professor Hitchcock's views as to the age of the rocks in the area along the Housatonic and Boston and Albany railroads. The Hinsdale pre-Cambrian is called Green Mountain gneiss; the hydromica-schist of Middlefield, Huronian.

1880. DANA (J. D.). Note on the age of the Green Mountains. Am. Jour. Sci., Vol. XIX, p. 191.

Only general considerations on this special region.

1881. HITCHCOCK (C. H.). Geological map of the United States and Territories. Julius Bien. Scale, 20 miles to an inch.

The gneisses are assigned to: "Gneisses of the Atlantic Slope, including Montalban," and "Metamorphic Paleozoic;" the valley rocks, to Lower or Cambro-Silurian (Lorraine to Calciferous).

1882. DANA (J. D.). Geological age of the Taconic system. Jour. Geol. Soc., Vol. XXXVIII, p. 397.

Refutation of Hunt's idea of the pre-Cambrian age of the Taconic. The map gives the slates and limestones, leaves the highlands uncolored, and writes over Bear Mountain, "Here some Archæan?"

1883–1885. KUNZ (George F.). Precious stones; from Mineral Resources of the United States, U. S. Geol. Survey.

1884. NEWBERRY (J. S.). Notes on building stones used in New York. Tenth Census, Vol. X, pp. 318–324.

Lee marble, uniform, not brilliant white, coarser than Vermont, finer than New York marbles. Strong and durable, has little iron, and becomes somewhat brown on exposure. This is thought by some to be an excellence. Not weakened by the change.

1884. MCGEE (W J). Map of the United States, exhibiting the present status of knowledge relating to the final distribution of geologic groups. (Preliminary compilation.) Compiled by W J McGee, 1884. Fifth Ann. Rept. U. S. Geol. Survey, Pl. II.

All the region given as Azoic-Archean.

1884. HITCHCOCK (C. H.). Geological map of the United States, in The National Atlas. Grey, Philadelphia.

1884. DANA (J. D.). On the decay of quartzite and the formation of sand, kaolin, and crystalline quartz. Am. Jour. Sci., Vol. XXVIII, p. 448.

1. Sand from quartzite. 2. Feldspathic quartzite the source of the kaolin. 3. Pseudobreccia from quartzite and in some of this pseudobreccia crystallized quartz.

1884. HAWES (G. W.), KELLEY (C.), MERRILL (G. P.), and SHALER (N. S.). Report on the building stones of the United States. Tenth Census, Vol. X.

Muscovite-biotite-gneiss of the Chester Granite Company, called Archean, p. 54.

1884. WHITNEY (J. D.) and WADSWORTH (M. E.). The Azoic system, Vermont and western Massachusetts. Bull. Mus. Comp. Zool., Vol. VI, p. 440.

So far as relates to our area, the section is almost wholly devoted to an accurate and detailed exposition of T. Sterry Hunt's views on the Taconic system and its remarkable metamorphoses. It is thus wholly given to a discussion of post-Azoic rocks and rocks it recognizes as such, and does not mention any of the rocks or areas of pre-Cambrian age in this territory.

1885. MERRILL (George P.). The collection of building and ornamental stones in the United States National Museum. A handbook and catalogue. Rept. Smith. Inst., 1885–86, Part II, pp. 277–648, Pls. I–IX.

1885. DANA (J. D.). Decay of quartzyte: Pseudo-breccia. Am. Jour. Sci., Vol. XXIX, p. 57.

Explains the breccias by the wedging action of crystallizing iron compounds.

1885. (1883–84.) HUNT (T. S.). The Taconic question in geology. The "Taconian" is a late pre-Cambrian formation. Trans. Can. Roy. Soc., Vol. I, Pt. 4, p. 227; Vol. II, p. 125.

1885. DANA (J. D.). On Taconic rocks and stratigraphy, with a geological map of the Taconic region. Am. Jour. Sci., Vol. XXIX, pp. 205, 437.

1886. Topographical map of the State of Massachusetts. Executed by the United States Geological Survey, at the joint expense of the State and the Survey.

Scale 1:62,500; 20-foot contours in brown; water in blue; roads in black.

1887. DANA (J. D.). On Taconic rocks and stratigraphy, with a geological map of the Taconic region. Am. Jour. Sci., Vol. XXXIII, p. 270.

Also published separately, with 1885 part.

1888. Geology of Berkshire County. Child's Berkshire County Gazetteer, pp. 24–26.

Inadequate and worthless.

1888. WALCOTT (C. D.). The Taconic system of Emmons, with map covering western border of the area. Am. Jour. Sci., Vol. XXXV, pp. 229, 307, 394.

1889. MERRILL (George P.). Handbook and catalogue of building and ornamental stones in the United States National Museum. Rept. Smith. Inst., 1885–86, p. 277, Pls. I–IX.

1890. DANA (J. D.). Archæan axes of eastern North America. Am. Jour. Sci., Vol. XXXIX, p. 378.

1890. ———. Archæan limestone and other rocks in Norfolk, Connecticut. Am. Jour. Sci., Vol. XXXIX, p. 321.

R. H. Cornish writes of a limestone ledge with spinel and chondrodite on land of Mr. Ralph Cressey, near a spring southeast of his house.

1890. CROSBY (W. O.). Macfarlane's geological railway guide, 2d edition.

Gives character of rocks along Boston and Albany Railroad.

1890. EMERSON (B. K.). Porphyritic and gneissoid granites in Massachusetts. Bull. Geol. Soc. Am., Vol. I, p. 559.

Describes briefly the Archean areas and their bordering conglomerate-gneisses. The Hinsdale area is taken as type.

1891. WALCOTT (C. D.). Correlation papers: Cambrian. Bull. U. S. Geol. Survey, No. 81.

1891. MERRILL (G. P.). Stones for building and decoration. New York. John Wiley's Sons.

This adds nothing concerning building stones of Massachusetts to the handbook of the United States National Museum, 1885.

1892. HOBBS (William H.). Intergrowths of hornblende with augite in crystalline rocks. Science, Vol. XX, p. 354.

Augite surrounding hornblende, from the Cleveland mine.

1892. ———. Notes on some pseudomorphs from the Taconic region. Am. Geologist, Vol. X, p. 47.

Pseudomorphs of fibrolite and mica after feldspar.

1893. MCGEE (W J). Reconnaissance map of the United States, showing the distribution of the geologic system so far as known.

Compiled from data in possession of the Geological Survey. Berkshire *County*, uncolored.

1894. McGEE (W J). Preliminary geologic map of New York, exhibiting the structure of the State so far as known.

Prepared by W J McGee under the direction of James Hall. A rounded area wholly southwest of the true pre-Cambrian of Bear Mountain is assigned to Laurentian granite, including unclassified crystallines. The rest assigned to (Gg) Georgia formation, and (Strm) Metamorphic, Trenton, and Calciferous limestone.

1894. PUMPELLY (Raphael), WOLFF (J. E.), and DALE (T. Nelson). Geology of the Green Mountains in Massachusetts. Mon. U. S. Geol. Survey, Vol. XXIII.

Notice in Am. Jour. Sci., 1896, p. 146.

1895. DANA (J. D.). Manual of geology, 4th edition.

1895. SHALER (N. S.). The geology of the road-building stones of Massachusetts. Sixteenth Ann. Rept. U. S. Geol. Survey, Vol. II, p. 277.

Notice Am. Jour. Sci., 4th series, Vol. I, 1896, p. 489.

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